Forest Resources & Practices
Region II-III Reforestation
Annotated Bibliography
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INTRODUCTION

The Region II and III Forest Practices Reforestation Science and Technical Committee Literature Review and Annotated Bibliography compiles documents relevant to reforestation of commercial timber harvest areas in the boreal and transitional forests of southcentral and interior Alaska (see Fig. 1).

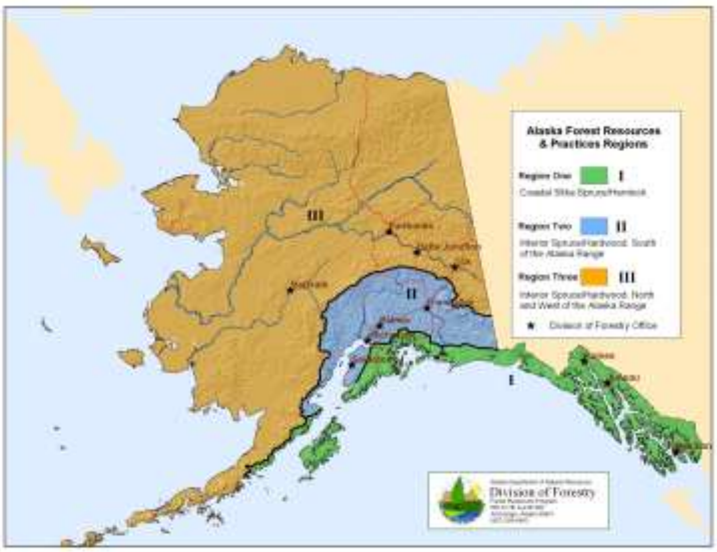

Figure 1. Map of Alaska Forest Resources and Practices Act regions.

Region II covers the boreal and transitional forests of south-central Alaska; Region III covers the boreal forests of interior Alaska.

The Alaska Forest Resources and Practices Act (FRPA, AS 41.17) governs commercial forestry operations on state, municipal, and private land. The Act is designed to protect fish habitat and water quality and ensure adequate reforestation while establishing management standards are workable for landowners and operators. The FRPA regulations in 11 AAC 95.375-.390 provide standards for reforestation and site preparation statewide.

In 2014, the Department of Natural Resources Division of Forestry and Department of Fish and Game Habitat Division, under the aegis of the Alaska Board of Forestry, began a review of the reforestation standards for Regions II and III. The departments convened an interdisciplinary committee to do the science and technical review. The committee included scientists and experienced resource managers with extensive knowledge about forest and wildlife management, forest ecology and silviculture, fire science, entomology, and climate change. This group, the Region II and III Reforestation Science & Technical Committee (S&TC) was charged with compiling and synthesizing the best available information regarding reforestation in these regions, reviewing the existing standards, and where needed, recommending changes to the standards to the Alaska Board of Forestry.

The Committee compiled information for the following categories:

- General background
- Silvics
- Reforestation methods and stocking standards
- Site preparation, competition control, and soils
- Fire and regeneration
- Wildlife-reforestation interactions
- Insects and disease
- Non-native and invasive species
- Climate change and assisted migration
- Reforestation modeling
- Regeneration assessment and technology

References for publications relevant to conditions in Region II and III were collected and annotated, and an introduction compiled for each section. The bibliography and introductions were submitted to the full committee for review and editing. This document compiles the eleven review topics.

The following people contributed to the compilation and/or synthesis of this information:

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Section 1
GENERAL BACKGROUND

SUMMARY

Marty Freeman, Alaska Department of Natural Resources, Division of Forestry

This section includes references that provide general background on the forest resources present in southcentral Alaska (Barrett and Christensen, 2011) and planting history in Alaska (Graham and Joyner, 2011). Ott (2005) lists ongoing forest research activity, including reforestation research in Alaska, and Puettmann and Ammer (2007) provide an overview of regeneration research trends in North American and Europe. Kneeshaw et al. (2000) discusses indicators of forest sustainability, include forest productivity from regeneration. Kerr (1999) emphasizes the importance of considering economic factors in determining reforestation standards.

REFERENCES

◆ **Barrett, T. M. and G.A. Christensen, eds. 2011.** Forests of southeast and south-central Alaska, 2004–2008: five-year forest inventory and analysis report. Gen. Tech. Rep. PNW-GTR-835. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 156 p.

Author abstract. This report highlights key findings from the most recent (2004–2008) data collected by the Forest Inventory and Analysis program across all ownerships in southeast and south-central Alaska. We present basic resource information such as forest area, ownership, volume, biomass, carbon sequestration, growth, and mortality; structure, and function topics such as vegetation and lichen diversity and forest age distribution; disturbance topics such as insects and diseases, yellow-cedar decline, fire, and invasive plants; and information about the forest products industry in Alaska, the potential of young growth for timber supply, biofuels, and nontimber forest products. The appendixes describe inventory methods and design in detail and provide summary tables of data and statistical error for the forest characteristics sampled.

◆ **Graham, J.S., and P.A. Joyner. 2011.** Tree planting in Alaska. Tree Planters Notes. 54(2):4-11

Author abstract. Tree planting for reforestation in Alaska has been modest compared with other timber-producing States and has never exceeded 1 million trees a year. Most timber harvest occurs in southeast Alaska, where natural regeneration is usually prolific and logistical costs are very high. Tree planting has been more suited to the boreal forest, where white spruce (*Picea glauca* (Moench) Voss) regeneration is sought and natural regeneration can be problematic. In the 1990s, a large spruce bark beetle (*Dendroctonus rufipennis* Kirby) epidemic on the Kenai Peninsula stimulated tree planting. Planting for poplars (*Populus* spp.) may develop near rural communities as biomass energy develops. Tree planting by homeowners and communities has been growing, which has resulted in the development of several community tree inventory programs and management plans. In 2010, approximately 1,600 trees were planted on municipal property or in public rights-of-way in Anchorage, and a much higher number is estimated to have been planted on private and other public land.

◆ **Kerr. C.L. 1999.** Levels of growing stock and economic returns. Pp. 19-21 in: Proc. of the Alaska Reforestation Council April 29, 1999 Workshop. Anchorage, AK. Univ. of Alaska Fairbanks Agric. & For. Exp. Sta. Misc. Publ. 99-8. 85 pp.

Author abstract. Current biological and social conditions on the Kenai Peninsula are putting significant negative economic pressure on private landowners. Biological and social (legal) conditions are driving most of the reforestation activity on private lands, but those who write regulations must also understand economic conditions. A guiding premise for the Alaska Forest Practice Act (FPA) is that economic criteria must be considered on at least an equal basis with other FPA concerns. This discussion provides preliminary information about the economic concerns of forest management in south-central Alaska.

◆ **Kneeshaw, D.D., Leduc, A., Drapeau, P., Gauthier, S., Pare, D., Carignan, R., Doucet, R., Bouthillier, L., Messier, C., 2000.** Development of integrated ecological standards of sustainable forest management at an operational scale. For. Chron. 76, 481-493.

Author abstract. Within Canada, and internationally, an increasing demand that forests be managed to maintain all resources has led to the development of criteria and indicators of sustainable forest management. There is, however, a lack of understanding, at an operational scale, how to evaluate and compare forest management activities to ensure the sustainability of all resources. For example, nationally, many of the existing indicators are too broad to be used directly at a local scale of forest management; provincially, regulations are often too prescriptive and rigid to allow for adaptive management; and forest certification programs, often based largely on public or stakeholder opinion instead of scientific understanding, may be too local in nature to permit a comparison of operations across a biome. At an operational scale indicators must be relevant to forest activities and ecologically integrated. In order to aid decision-makers in the adaptive management necessary for sustainable forest management, two types of indicators are identified: those that are prescriptive to aid in planning forest management and those that are evaluative to be used in monitoring and suggesting improvements. An integrated approach to developing standards based on an ecosystem management paradigm is outlined for the boreal forest where the variability inherent in natural systems is used to define the limits within which forest management is ecologically sustainable. Sustainability thresholds are thus defined by ecosystem response after natural disturbances. For this exercise, standards are proposed for biodiversity, forest productivity via regeneration, soil conservation and aquatic resources. For each of these standards, planning indicators are developed for managing forest conditions while forest values are evaluated by environmental indicators, thus leading to a continuous cycle of improvement. Approaches to developing critical thresholds and corresponding prescriptions are also outlined. In all cases, the scale of evaluation is clearly related to the landscape (or FMU) level while the stand level is used for measurement purposes. In this view the forest should be managed as a whole even though forest interventions are usually undertaken at the stand level.

◆ **Magoun, A.J., and F.C. Dean. 2000.** Floodplain forests along the Tanana River, interior Alaska: Terrestrial ecosystem dynamics and management considerations. Miscellaneous Publication 2000-3, Agricultural and Forestry Experiment Station, University of Alaska, Fairbanks. 139 p. [H]

Compiler abstract. This extensive and detailed literature review introduces the geomorphology and vegetation of the floodplain before characterizing forest succession, decomposition, wildlife ecology and habitat use, timber harvesting, and research needs. Although it focused on floodplain white spruce because these high volume stands were of interest during international export markets in the 1990s, the review includes substantial information on upland forest structure and processes for comparison and contrast. It serves as an excellent reference through 1999 on vegetation and wildlife.

◆ **Ott, R.A. 2005a.** Summaries of management and research activities related to Alaska's boreal forests. 2nd ed. Alaska Northern Forest Cooperative. Unpublished. 119 pp.

Compiler abstract: This document compiles summaries of published and unpublished management and research activities including information in the following categories:

- Climate variability and forests
- Fire management
- Forest community classification,
- Forest health,
- Forest inventory
- Site index
- Tree regeneration
- Tree thinning
- Tree volume equations
- Wildlife

◆ **Puettmann, K.J., and C. Ammer, 2007.** Trends in North American and European regeneration research under the ecosystem management paradigm. Eur. J. For. Res. 126, 1-9.

Author abstract. Forest management on many ownerships in North America and Europe has shifted toward the ecosystem management paradigm. The associated shift toward multiple management objectives and focus on natural development patterns should also be reflected in regeneration research efforts. As new information needs arise, research questions and approaches should be evaluated whether they are still appropriate. Specifically, spatial and temporal scales of research studies need to be expanded to accommodate complex sets of management objectives and constraints, rather than being focused on optimal tree regeneration. At the same time, silviculturists are asked to utilize natural trends as a guide for management, but most natural disturbance studies have focused on stand structures and not the regeneration processes. Criteria commonly used to describe disturbance regimes need to be modified to better guide regeneration research efforts under the ecosystem management paradigm.

Section 2
SILVICS

SUMMARY

John Yarie, School of Natural Resources & Extension, University of Alaska Fairbanks
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The term "silvics" has been defined as "the study of the life history and general characteristics of forest trees and stands with particular reference to environmental factors, as a basis for the practice of silviculture" (SAF 1998).

Fox (1999) suggested that the general public will start to see a more realistic view of the sustainability of forest values. This will be enhanced by the increased demand for fuel wood now and in the future. Tree reproduction will start to become a much more important issue followed by the natural growth rates that will occur in the future tied to climate change dynamics. All of these factors will be closely tied to the "silvics" of the species that are currently present on the landscape and the potential exotic species that might be established in the future all tied to climate change dynamics.

Seedling establishment and regeneration. Environmental factors that influence natural regeneration are seed production, dispersal, germination and seedling establishment basically for all boreal species but differences in these processes can dictate the species composition of the new forest — pure spruce to pure hardwoods to various levels of mixed-wood stands. Regeneration following disturbance tied to the changing climate will be a key factor to control vegetation dynamics across the boreal forest. The regeneration dynamics will depend on the type and severity of the disturbance. Bare mineral soil is considered to be the best substrate for seed regeneration of the species currently present in interior Alaska. However insect and disease mortality results in very little disturbance to the forest floor and seed regeneration has drastically lower potential compared to stump and root sprouting by both birch and aspen, respectively.

Seed availability is an important factor tied to regeneration dynamics. Most of the interior Alaska species show variability in the time of good seed crops. Birch has shown good seed production with high viability about every other year, aspen about every 4 to 5 years, white spruce every 6 to 10 years. High levels of black spruce seed production occur about every 4 to 8 years, but due to the serotinous cones high quantities of viable seed may be present in the tree crowns. Black spruce cone production usually starts about year 30 but seed quality is relatively low till about age 50. This suggests that you need approximately a 50-year fire return interval for black spruce ecosystems to suggest a return of black spruce to the same site.

Black spruce cone production did not decrease over a latitudinal gradient but seeds/cone, percentage of filled seeds and germination percentage did decrease in a northward trend. Black spruce seed production was found to be limited close to tree line by climate characteristics and the possibility of a poor seedbed (lack of frequent fire). It was also reported that there was an inconsistency in seed production cycles across the landscape at distances greater than three kilometers.

Succession. Ecosystem structural dynamics can be very different dependent upon the disturbance dynamics that have taken place. An ecosystem affected by fire will be structurally different than an ecosystem affected by insects or disease. In both cases two types of successional pathways are possible. One, canopy-dominant tree species replace themselves resulting in a relatively unchanging forest. This pattern can be termed as self-replacement. A different pathway called species-dominance relay involves simultaneous post-fire establishment of multiple tree species followed by canopy dominance shifts controlled by the autecology of the species present. It has been suggested that as climate change occurs species-dominance relay will decrease. Based on successional studies it has been suggested that fire should be used for site preparation of white spruce ecosystems if a self-replacement sequence is desired for a fast return to a white spruce ecosystem

In a study dealing with climate change dynamics and tree line advance (Wilmking 2003) it was suggested that this process will not be straight forward. Tree line advance will be dependent on the elevation and latitude of the current tree line and the spring weather events under climate change

Growth and forest ecosystem management. It has been suggested that as a result of climate change spruce growth will decline in eastern interior Alaska and increase in western interior Alaska. These differences are suggested as a result of potential precipitation differences that could occur in the future. If a species dominance pathway is present, then species competition will play a large role in ecosystem dynamics. It has been found that overtopping or shading significantly decreased growth of white spruce seedlings. Mortality was not indicated as increasing but slower growth was present. Looking at the light requirements of white spruce it was found that approximately 40% of full sunlight was required to maximize the growth of understory white spruce. Levels above did not show an increase in growth. However the competition canopy structure may play a major role in determine the amount of sunlight that is reaching the understory. Height growth in an aspen understory for white spruce was equal to what was found in open grown clearcut areas in west-central Alberta.

Management of white spruce ecosystems can range from an even-aged structure to an uneven-aged structure depending on the overall goals of the landowner. This can be tied to the objectives of the land owner and their potential vision for combining stand-level and landscape-level management. Stand level management and landscape level management can lead to different overall landscape structure. At the stand level, managers may concentrate on the even-aged management direction while at the landscape perspective more variability in ecosystem structure may bring in a larger number of uneven-aged stands.

Uneven-aged stands may result in low ingrowth (regeneration) of spruce in the existing stand (P. abies in Sweden) after harvesting, but overall tree mortality in the stand may also be low so there is sufficient survival to maintain the overall uneven-aged stand structure.

Regeneration management in interior Alaska was thought to require planting seedlings within 10 years of cutting. However recent studies have suggested that natural regeneration overwhelmed the density of planted seedlings. The one major difference was the distribution of trees across the area. In the planting procedure seedlings were equally spaced across the entire cutover area while using natural regeneration the seedling distribution was somewhat clumped.

Finally the presence of old-growth forest ecosystems across the landscape may be a key component for maintenance of biodiversity at the landscape level. The old-growth stage is characterized by small-scale disturbances that engender gap dynamics. This could lead to uneven-aged stands and an increase in landscape biodiversity. Major disturbances will cause an elimination of old-growth in various areas but in interior Alaska are a natural part of the landscape ecosystem dynamics

REFERENCES

◆ **Adams, P.C. 1999.** The dynamics of white spruce populations on a boreal river floodplain . Unpubl. PhD Thesis, Duke University. 178 pp.

Author abstract. Studies of forest development on river floodplains in interior Alaska have asserted that succession is linear and directional. Beginning with the invasion of willows on newly formed silt bars, subsequent fluvial depositional builds terraces of increasing height and distance from the river on which successive communities of alder, balsam poplar, white spruce, and eventually black spruce develop. This classical model assumes that primary succession is a deterministic autogenic process in which early successional species facilitate the establishment of late successional species through environmental modification. I focused on the dynamics of white spruce establishment and growth in this successional environment. My primary objective was to describe boreal floodplain white spruce forests and the major environmental and biotic constraints on their development. I examined factors affecting the age, growth and spatial structure of white spruce populations across successional sere. Ecosystem processes on the Tanana River floodplain are closely linked to fluvial processes, and these in turn are directed by climate. Patterns of deposition and erosion resulting in the building and removal of successional terraces are functions of the climate controlled river discharge fluctuations, and are neither continuous nor directional. White spruce occurs as seedlings, saplings, and seed-producing trees throughout the primary successional sequence, and its age structure reflects past variation in recruitment and mortality rates. Successful seedling establishment is episodic and correlated with a combination of interacting environmental and biotic factors, including silt deposition accompanying floods, seed production and dispersal, and herbivory of seedlings by snowshoe hares. Both herbivory and low light under canopies reduce seedling height growth. The relative influence of some of these factors changes through succession because of interactions with the developing vegetation. Radial growth patterns of mature floodplain white spruce trees differ from those of nearby upland trees in their reduced sensitivity to climate variability because of the high water table on the floodplain. Although elements of the classic facilitation model of succession are consistent with some of my results, much of the spatial and temporal variability in patterns of white spruce establishment and growth can be attributed to episodic environmental and biotic factors throughout the succession.

◆ **Brassard, B.W., Chen, H.Y.H. 2006**. Stand structural dynamics of North American boreal forests. Crit. Rev. Plant Sci. 25, 115-137.

Author abstract. Stand structure, the arrangement and interrelationships of live and dead trees, has been linked to forest regeneration, nutrient cycling, wildlife habitat, and climate regulation. The objective of this review was to synthesize literature on stand structural dynamics of North American boreal forests, addressing both live tree and coarse woody debris (CWD) characteristics under different disturbance mechanisms (fire, clearcut, wind, and spruce budworm), while identifying regional differences based on climate and surficial deposit variability. In fire origin stands, both live tree and CWD attributes are influenced initially largely by the characteristics of the stand replacing fire and later increasingly by autogenic processes. Differences in stand structure have also been observed between various stand cover types. Blowdown and insect outbreaks are two significant non-stand replacing disturbances that can alter forest stand structure through removing canopy trees, freeing up available growing space, and creating microsites for new trees to establish. Climate and surficial deposits are highly variable in the boreal forest due to its extensive geographic range, influencing stand and landscape structure by affecting tree colonization, stand composition, successional trajectories, CWD dynamics, and disturbance regimes including regional fire cycles. Further, predicted climate change scenarios are likely to cause regional-specific alterations in stand and landscape structure, with the implications on ecosystem components including wildlife, biodiversity, and carbon balance still unclear. Some stand structural attributes are found to be similar between clearcut and fire origin stands, but others appear to be quite different. Future research shall focus on examining structural variability under both disturbance regimes and management alternatives emulating both stand replacing and nonstand replacing natural disturbances.

◆ **Brown, K. R., D.B. Zobel, and J.C. Zasada. 1988.** Seed dispersal, seedling emergence, and early survival of Larix laricina (duroi) k. koch in the Tanana Valley, Alaska . Canadian Journal of Forest Research 1988, v. 18, no. 2 (Mar. 1988) pp. 306-314.

Author abstract. The seasonal and spatial patterns of seed release, germling emergence, and early survival of *Larix laricina* (DuRoi) K. Koch were studied in 1980–1981 near Fairbanks, Alaska. Dispersal was studied on one wetland site. Seedling emergence and 1-year survival were studied on three wetland microsite types (troughs, feathermoss, and tussock tops, located at increasing elevations above permafrost) and in mineral soil and undisturbed feathermoss seedbeds in a mature *Picea glauca* stand of alluvial origin. Approximately 95% of the viable *Larix* seed from the 1980 cone crop fell by November 1980. Spatial distribution of seed away from the stand was erratic because of variable winds and the presence of a single *Larix* away from the stand edge. Average dispersal distances were less than those reported for other coniferous species. Emergence and early survival in both site types were affected by seedbed type. In the alluvial stand, germination and 1-year survival were greater on mineral seedbeds than on feathermoss. Emergence began in mid-July, well after minimum temperatures required for germination had been reached; timing appeared to be related to differences in volumetric moisture contents of the two seedbed types. Although cumulative totals of emergence and mortality did not differ between microsite types in the wetland, seasonal patterns of each differed with microsite. Emergence in troughs was delayed until early July by cold seedbed temperatures; increased precipitation in mid to late July raised the water table and flooded newly emerged seedlings in trough microsites but moistened feathermoss sufficiently to promote germination. Variation in emergence and mortality was high within a given microsite type.

◆ **Burns, R.M. and B.H. Honkala, tech. coordinators. 1990.** Silvics of North America: v.1. Conifers; v.2. Hardwoods. U.S. Forest Service, Washington, DC. Agric. Handbook 654. 877 p.

Author abstract. The silvical characteristics of about 200 forest tree species and varieties are described. Most are native to the 50 United States and Puerto Rico, but a few are introduced and naturalized. Information on habitat, life history, and genetics is given for 15 genera, 63 species, and 20 varieties of conifers and for 58 genera, 128 species, and 6 varieties of hardwoods. These represent most of the commercially important trees of the United States and Canada and some of those from Mexico and the Caribbean Islands, making this a reference for virtually all of North America. A special feature of this edition is the inclusion of 19 tropical and subtropical species. These additions are native and introduced trees of the southern border of the United States from Florida to Texas and California, and also from Hawaii and Puerto Rico.

◆ **Chrimes, D., 2004**. Stand development and regeneration dynamics of managed uneven-aged Picea abies forests in boreal Sweden, Doctor’s Dissertation. Swedish University of Agricultural Sciences, Department of Silviculture. Umeå Sweden.

Author abstract. Volume increment and ingrowth are important aspects of stand development and regeneration dynamics for determining the effectiveness of uneven-aged silvicultural systems. The main objectives of this thesis were to establish the influence of standing volume on volume increment after different kinds of harvest regimes, the influence of overstorey density on height growth of advance regeneration, and the influence of bilberry (Vaccinium myrtillus L.) on spruce regeneration in managed uneven-aged Norway spruce (Picea abies (L.) Karst.) forests in boreal Sweden. Model simulations with 5-year growth iterations and three harvest regimes of diameter-limit, single-tree selection, and schematic harvests were used to investigate the influence of standing volume on volume increment. Additionally, field experiments at two sites, re-inventoried ten years after treatments that had a 3×2 factorial design of three thinning intensities (30, 60, 85% of pre-harvest standing volume) and two types of thinning (harvested larger or smaller trees), were used. The influence of overstorey density on height growth was established using one of the sites that measured height increments of seedlings, saplings, and small trees in the plots. A field investigation was carried out to establish the influence of bilberry on spruce saplings, which cut bilberry stems in 1 m2 circle plots around treated saplings and their height growth compared to the control saplings with uncut bilberry stems.

Volume increment increased with increasing standing volume, culminated, and eventually declined. The highest volume increment was found for diameter-limit harvests followed by single-tree selection and schematic harvests. For harvesting a residual stand to 50 m3ha-1, the schematic harvest showed increment losses equaling 25 years of growth. For the field experiments at both sites, standing volume was correlated significantly positively ($p<0.05$) with volume increment. Only for the more productive site, standing volume was correlated significantly negatively ($p<0.05$) with ingrowth. The height increments for all spruce advance regeneration were better correlated with canopy openness than with basal area or standing volume. Treated saplings decreased in height increment compared to the control during the first and second year after cutting bilberry.

In conclusion, volume increment increased with increasing standing volume and harvesting mostly the larger trees in a residual stand with large number of stems and large number of small trees yields high volume increments. At both sites the ingrowth of spruce regeneration was low, but higher than mortality and the number of trees removed, and thus it was sufficient to replace the harvested trees. The cutting of bilberry reduced the height growth of spruce regeneration.

◆ **Cole, E.C., M. Newton, and A. Youngblood. 2013.** Effects of overtopping on growth of white spruce in Alaska. Can. J. For. Res. 43(9): 861-871, 10.1139/cjfr-2013-0117

Author abstract. Early establishment of competing vegetation often presents an obstacle to the success of planted white spruce (*Picea glauca* (Moench) Voss) seedlings. We followed growth and development of white spruce and associated vegetation for up to 17 years in Alaska's boreal forests to quantify roles of overtopping plant cover in suppressing conifers. The three study areas represented a range of site conditions of varying productivity and species of competing cover, different site preparation and release treatments, and different bare-root and container white spruce stock types. Herbaceous overtopping peaked early after planting and decreased as white spruce were able to outgrow competitors. Overtopping by shrubs and hardwoods, especially aspen (*Populus tremuloides* Michx.) and resin birch (*Betula neoalaskana* Sarg.) peaked somewhat later than herbaceous overtopping and decreased over time for most sites and treatments. In a model that combined all sites, vegetation management treatments, and years, overtopping and previous year's volume explained approximately 85% of the variation in volume growth. Increasing the size of planting stock helped reduce overtopping, hence suppression, even in treatments dominated by hardwood species. Results suggested that control of overtopping was essential for maximum growth and long-term or increasing levels of overtopping severely suppressed white spruce seedling growth.

◆ **Drake, G.L. 1965.** Birch-spruce forests of the upper Cook Inlet region of Alaska . USDA Forest Service, U.S. G.P.O. 11 pp.

Author abstract. Twenty years ago the name Alaska brought to the mind a vast treasure house of gold; today we think of Alaska as one of the coming centers of the pulp industry, and twenty years hence may see southwestern and central Alaska the home of many wood-working plants, utilizing the Alaska birch. The recent completion of the government railroad from Seward to Fairbanks, which passes through the birch-spruce forest for the major part of its distance, has made these forests accessible. The birch-spruce forests lie on two great watersheds—the Susitna, which drains west into Cook Inlet, and the Yukon which drains north into Bering Sea. This article treats of the forests of the Upper Cook Inlet country as they, due to their greater accessibility, will be exploited before the vast forests of the Yukon country. During the summer of 1916 the writer while on timber sale administrative work along the government railroad in the Cook Inlet region had an opportunity to study these birch-spruce forests. Only a portion of the area was traversed in the field and the number of trees which form the basis of the tables was limited, but it is felt this information will be of interest to the profession as it deals with a region and species of which little is known.

◆ **Feng, Z., K.J. Stadt, and V.J. Lieffers. 2006.** Linking juvenile white spruce density, dispersion, stocking, and mortality to future yield. Canadian Journal of Forest Research, 36: 3173–3182.

Author abstract. We examined methods of linking density, dispersion, and stocking information from juvenile regeneration surveys with mortality estimates to predict future yield of white spruce (Picea glauca (Moench) Voss) in boreal mixedwoods. The study focused on data from 709 stands (7–150 years) and defined a stocked plot (10 m2) as having one or more acceptable trees. In juvenile surveys, ingress of natural spruce overwhelmed the regular planting pattern, creating clumped dispersion patterns, as indicated by the Morisita index. A function was developed to describe the relationship between stocking, density, and dispersion. In mature, permanent sample plots, only 30%–40% stocking of 10 m2 plots (700 stems/ha–1) was needed to achieve full yields. Mortality rates for planted spruce varied from 0.1% to 0.8% per year for juvenile stands and from 1.7% to 3.3% per year for mature stands. For rotation-length predictions in Alberta, 0.7% per year is likely a mean mortality loss. These findings were combined to generate stocking versus time curves at a range of mortality rates. The tallest spruce measured in each juvenile survey plot had the same mortality rate regardless of absolute size, and spruce mortality was reduced when associated with aspen. These findings call into question minimum height requirements and free-to-grow criteria in regeneration standards.

◆ **Fox, J.D. 1999.** Long-term public uses of Alaska's forests: Influence of stocking standards. pp. 27-31 in: Proc. of the Alaska Reforestation Council April 29, 1999 Workshop. Anchorage, AK. Univ. of Alaska Fairbanks Agric. & For. Exp. Sta. Misc. Publ. 99-8. 85 pp.

Author abstract. This paper describes three scenarios of future global development as a backdrop to projections and speculations about long-term public uses of Alaska's forests. Emphasis is on population and economic growth trends and implications for a growing dichotomy between the "haves" and the "have nots." The author projects an increase in public demand for both commodity and amenity values from forests. In the short run, he sees a continuation of the public delusion that the forest life cycle can be sustained without tree death. This will be followed by a rude awakening to the realities of nature and a moderation of the paranoia over timber harvest. He notes that forests are an end in themselves, not just a means, and criticizes economic analysis that fails to make that distinction. He encourages foresters to "keep the faith" – the faith that people will always prefer to live with forests rather than without them – and to commit acts of faith by planting trees.

◆ **Gärtner, S. M., V. J. Lieffers, and S. E. Macdonald. 2011**. Ecology and management of natural regeneration of white spruce in the boreal forest. Environmental Reviews 19:461-478.

Author abstract. Most forest managers view natural regeneration of Picea glauca (white spruce) after forest harvesting to be unreliable; in this paper the Authors dispute this idea by describing the factors influencing natural regeneration of spruce, i.e., seed production, dispersal, germination and seedling establishment and discussing the opportunities for encouragement of natural regeneration after logging. Seed supply is greatest from trees with large crowns, that are positioned in the upper canopy and seeding is greatest in mast years. Maintaining at least five mature white spruce trees per hectare within cut areas or dense stands of spruce on edges of cutovers ensures pollination success as well as even seed distribution. The most suitable seedbeds for white spruce germination are mineral soil, mineral soil with a thin organic layer, or large downed rotten logs. Mineral soil seedbeds are available for a short time after fire or other disturbances, while downed wood becomes available over time; this results in recruitment immediately after disturbance or several decades later. To increase the availability of suitable seedbeds the soil can be scarified during or after harvest and nurse logs should be left; on wet sites mounding should be considered. Partial canopy cover can protect seedlings from climate extremes while limiting competing vegetation. Using natural regeneration, a range of stocking outcomes can be expected — from no stocking to overstocking of spruce. Such variation in the amount of spruce versus broadleaf species, however, is consistent with the range of variation in forest composition found naturally in the boreal mixedwood region.

◆ **Greene, D. F., Zasada, J. C., Sirois, L., Kneeshaw, D., Morin, H., Charron, I., and Simard, M. J. 1999.** A review of the regeneration dynamics of North American boreal forest tree species. Canadian Journal of Forest Research, 29: 824-839.

Author abstract. In this review, we focus on the biotic parameters that are crucial to an understanding of the recruitment dynamics of North American boreal tree species following natural (fire, budworm infestation, windthrow) or human induced (clearcut, partial cut) disturbances. The parameters we emphasize are (i) the production of seeds and asexual stems (both of which, we argue, are a function of basal area density), (ii) the dispersal of seeds by wind (or the dispersion of asexual stems) as a function of distance from source, (iii) dormant seed bank capacity, (iv) organic layer depth as a determinant of germinant mortality and asexual bud response, and (v) shade tolerance as a partial arbiter of the density of advanced regeneration. Having identified the gaps in our knowledge, we conclude by suggesting a short term research agenda whose completion would lead to the parameterized functions that would constitute the recruitment subroutine in a landscape-scale forest dynamics simulator.

◆ **Harvey, B.D., Leduc, A., Gauthier, S., Bergeron, Y., 2002.** Stand-landscape integration in natural disturbance-based management of the southern boreal forest. For. Ecol. Manage. 155, 369-385. Johnstone, J., Chapin, F., 2006. Effects of soil burn severity on post-fire tree recruitment in boreal forest. Ecosystems 9, 14-31.

Author abstract. Forest ecosystem management, based partly on a greater understanding of natural disturbance regimes, has many variations but is generally considered the most promising approach to accommodating biodiversity concerns in managed forested regions. Using the Lake Duparquet Forest in the southeastern Canadian boreal forest as an example, we demonstrate an approach that attempts to integrate forest and stand-level scales in biodiversity maintenance. The concept of cohorts is used to integrate stand age, composition and structure into broad successional or stand development phases. Mean forest age (MFA), because it partly incorporates historic variability of the regional fire cycle, is used as a target fire cycle. At the landscape level, forest composition and cohort objectives are derived from regional natural disturbance history, ecosystem classification, stand dynamics and a negative exponential age distribution based on a 140 year fire cycle. The resulting multi-cohort structure provides a framework for maintaining the landscape in a semi-natural age structure and composition. At the stand level, the approach relies on diversifying interventions, using both even-aged and uneven-aged silviculture to reflect natural stand dynamics, control the passage ("fluxes") between forest types of different cohorts and maintain forest-level objectives. Partial and selective harvesting is intended to create the structural and compositional characteristics of mid- to late-successional forest types and, as such, offers an alternative to increasing rotation lengths to maintain ecosystem diversity associated with over-mature and old-growth forests. The approach does not however supplant the necessity for complementary strategies for maintaining biodiversity such as (lie creation of reserves to protect rare, old or simply natural ecosystems. The emphasis on maintaining the cohort structure and forest type diversity contrasts significantly with current even-aged management in the Canadian boreal forest and has implications for stand-level interventions, notably in necessitating a greater diversification of silvicultural practices including more uneven-aged harvesting regimes. The approach also presents a number of operational challenges and potentially higher risks associated with multiply stand entries, partial cutting and longer intervals between final harvests. There is a need for translating the conceptual model into a more quantitative silvicultural framework. Silvicultural trials have been established to evaluate stand-level responses to treatments and operational aspects of the approach.

◆ **Hynynen, J., P. Niemistö, A. Viherä-Aarnio, A. Brunner, S. Hein, and P. Velling. 2010.** Silviculture of birch (Betula pendula Roth and Betula pubescens Ehrh.) in northern Europe. Forestry 83:103-119.

Author abstract. In Europe, two commercially important treelike birch species occur naturally: silver birch (Betula pendula Roth) and downy birch (Betula pubescens Ehrh.). Both species have a wide natural distribution area on the Eurasian continent, ranging from the Atlantic to eastern Siberia. Although birches occur throughout almost the whole of Europe, the most abundant birch resources are in the temperate and boreal forests of Northern Europe. In the Baltic and Nordic countries, the proportion of birch out of the total volume of the growing stock varies between 11 and 28 per cent. In Northern Europe, birch is commercially the most important broadleaved tree species.

Birches are light-demanding early successional pioneer species, which grow both in mixed stands and in pure stands. This article provides an overview of the most important ecological characteristics and typical growth and yield patterns of birch, based on European scientific literature. Growth and yield research on birch has been relatively active in Northern Europe, where numerous growth and yield models have been developed during the last decades. In this paper, a list of published scientific articles on growth modelling is provided and is grouped according to the different types of model.

When growing in forest stands, birches have a relatively straight slender stem form. The current practices and silvicultural recommendations, based on research directed at high-quality timber production in silver birch stands, are reviewed. Although the emphasis is on even-aged pure silver birch stands, the management of mixed stands as well as the silviculture of downy birch and curly birch are also briefly discussed.

◆ **Juday, G.P. 2013.** Monitoring Hectare-Scale Forest Reference Stands At Bonanza Creek Experimental Forest LTER. In: Camp, A.E.; Irland, L.C.; Carroll, C.J.W. (eds.) Long-term Silvicultural & Ecological Studies: Results for Science and Management, Volume 2.

Author abstract. A long-term forest ecological monitoring project has been underway on the Bonanza Creek Experimental Forest (BCEF) in central Alaska since 1986.

◆ **Kabzems, R.D., G. Harper, and P. Fielder. 2011.** Growing Space Management in Boreal Mixedwood Forests: 11-Year Results. Western Journal of Applied Forestry, Volume 26, Number 2, April 2011, pp. 82-90(9).

Author abstract. Managing boreal mixed stands of trembling aspen (Populus tremuloides Michx.) and white spruce (Picea glauca [Moench] Voss) is more likely to sustain a diversity of values and has the potential to increase productivity at both the site and landscape levels compared with pure broadleaf or conifer management. In this study, we examine growth of white spruce and aspen after 11 growing seasons over a range of aspen densities created by spot and broadcast treatment of broadleaves using manual and chemical means, aspen spacing, and an untreated control. Results indicate that survival and growth of both spruce and aspen were similar across the range of treatments. Spruce groundline diameter was greater, and height to groundline diameter ratio was lower, for the treatments in which aspen was chemically controlled or uniformly spaced compared with the control. Light measurements at the individual tree level suggested that increased light availability improved white spruce diameter growth. Spruce height growth did not vary by treatment. The status of these experimental mixedwoods was compared with current conifer and mixedwood regeneration evaluations, as well as the preharvest composition of the original stand. After 11 growing seasons, growth of aspen and white spruce indicated that opportunities exist to further modify aspen density to enhance treatment longevity and effectiveness to produce a greater range of boreal mixedwood stand types.

◆ **Kneeshaw, D.D. and Y. Bergeron. 1998**. Canopy gap characteristics and tree replacement in the southeastern boreal forest. Ecology 79, 783-794.

Author abstract. This study identifies patterns in the gap disturbance regime along a successional gradient in the southern boreal forest and uses this information to investigate canopy composition changes. Gaps were characterized in hardwood, mixed-forest, and conifer stands surrounding Lake Duparquet in northwestern Quebec. From 39 to 80 gaps were evaluated along transects established in each of these stands. The abundance of gap makers and gap fillers and total regeneration was evaluated by species, as well as the size of each gap encountered along the transects. The percentage of the forest in canopy gap was calculated directly from the proportion of the transect in gap and by using gap area and line intercept techniques. Changes in composition were evaluated from gap-maker and gap filler distributions and by using transition matrices based on species mortality and regeneration in canopy gaps. The percentage of the forest in canopy gap ranges from 7.1% in a 50-yr old forest dominated primarily by aspen to 40.4% in a 234-yr-old fir-dominated forest. Gap events are due to individual or small-group tree mortality in the early successional forest but become species-specific events controlled by spruce budworm outbreaks in the later stages of succession. Due to the high latitude, direct light only reaches the forest floor in the very largest gaps of the conifer-dominated stands. However, these gaps form slowly as budworm caused mortality occurs over a number of years, whereas in aspen-dominated stands gaps are formed quickly by the snapping of tree stems. Balsam fir is the most abundant gap filling species; however, its abundance is negatively correlated to gap size in all stand types. Markovian transition matrices suggest that in the young aspen-dominated forests small gaps lead to species replacement by more shade-tolerant conifers but that in the oldest forests the larger gaps will result in maintenance of the intolerant species and an increase in the abundance of cedar.

◆ **Kneeshaw, D. and S. Gauthier. 2003**. Old growth in the boreal forest: A dynamic perspective at the stand and landscape level. Environmental Reviews 11:S99-S114.

Author abstract. Old-growth forests have been identified as a potentially important stage of stand development for maintaining biodiversity in the landscape, yet they have also been targeted by the forest industry in their drive to regulate the forest. We will attempt to propose a definition of old growth, applicable throughout the North American boreal forest, that takes into account the dynamic nature of forest development and that could be useful for management and conservation purposes. We define the start of the old-growth stage as occurring when the initial post-disturbance cohort begins dying off, concurrent with understory stem recruitment into the canopy. We propose that species longevity and the regional fire cycle can be used to assess the extent of this phase in different regions. Using published data on fire history, we show that the amount of old growth expected to occur in western and central Canada is less than in eastern Canada, where most stands (in area) escape fire for periods longer than that necessary to incur substantial mortality of the initial cohort. At the stand level, we show that the old-growth stage is characterized by small-scale disturbances that engender gap dynamics. Until recently, this process had not been studied in the boreal forest. The old-growth index we present suggests that the relationship between time since the last major disturbance and old growth status varies most in areas that have not been disturbed for long periods. Both management and conservation strategies have to take into account that old-growth forests are dynamic. To be effective, reserves should contain all stages of development and should be sufficiently large to encompass rare but large disturbances. The abundance of old growth in many boreal regions of North America also suggests that forest management strategies other than even-aged, fully regulated systems have to be developed.

◆ **Kurkowski, T.A., D.H. Mann, T. S. Rupp, D. L. Verbyla. 2008**. Relative importance of different secondary successional pathways in an Alaskan boreal forest. CJFR , 2008, 38(7): 1911-1923, 10.1139/X08-039

Author abstract. Postfire succession in the Alaskan boreal forest follows several different pathways, the most common being self-replacement and species-dominance relay. In self-replacement, canopy-dominant tree species replace themselves as the postfire dominants. It implies a relatively unchanging forest composition through time maintained by trees segregated within their respective, ecophysiological niches on an environmentally complex landscape. In contrast, species-dominance relay involves the simultaneous, postfire establishment of multiple tree species, followed by later shifts in canopy dominance. It implies that stand compositions vary with time since last fire. The relative frequencies of these and other successional pathways are poorly understood, despite their importance in determining the species mosaic of the present forest and their varying, potential responses to climate changes. Here we assess the relative frequencies of different successional pathways by modeling the relationship between stand type, solar insolation, and altitude; by describing how stand age relates to species composition; and by inferring successional trajectories from stand understories. Results suggest that >70% of the study forest is the product of self-replacement, and tree distributions are controlled mainly by the spatial distribution of solar insolation and altitude, not by time since last fire. As climate warms over the coming decades, deciduous trees will invade cold sites formerly dominated by black spruce, and increased fire frequency will make species-dominance relay even rarer.

◆ **Lamontagne, J. M. and S. Boutin. 2007.** Local-scale synchrony and variability in mast seed production patterns of *Picea glauca*. Journal of Ecology, 95: 991–1000. doi: 10.1111/j.1365-2745.2007.01266.x

Author summary. Mast seeding is the synchronous and highly variable production of seed by a population of plants. Mast seeding results from the behaviour of individuals; however, little is known about the synchrony of individuals at local scales. We address two primary questions at a within-population (17–36 ha study plots) and individual level: (i) How variable is seed production between and within years? (ii) How synchronized is seed production between individuals? We monitored annual cone production of 356 *Picea glauca* (white spruce) from 1990 to 2005 within four plots spanning a total distance of 5.3 km in the Yukon Territory, Canada. Spearman correlations (r_s) were conducted to test for synchrony. Overall, the trees were moderately synchronous (mean r_s (± SE) of 0.52 ± 0.14), and synchrony was statistically detectable ($r_s > 0$) over all distances. Individuals < 75 m apart were highly synchronous (0.64 ± 0.18), and correlations dropped to 0.33 ± 0.07 for trees > 3 km apart. There was considerable variation in cone production patterns among pairs of individuals. The number of mast years per plot varied from one to three. During a mast year, many individuals within plots produced large cone crops, with more variability between individuals in low mean cone years. Individual trees had dominant endogenous cycles varying from none to 1–5 years. Forty-four per cent of trees had no significant lag, 23% a negative 1-year lag, and 20% a positive 3-year lag. Basal area did not influence lags, but trees with higher mean cone production throughout the study were more likely to have a 3-year lag compared with no lag. The scale of highest synchrony coincided with the scale at which the dominant seed predator in the area, the territorial red squirrel (*Tamiasciurus hudsonicus*), operates. This may be the scale at which selection for synchrony occurs. Based on high synchrony locally, high synchrony within a mast year, and multiple lags in cone production by individuals, both available resources and strong weather cues appear to play roles in the observed patterns.

◆ **Lieffers, V. J. and K. J. Stadt. 1994.** Growth of understory Picea glauca, Calamagrostis canadensis, and Epilobium angustifolium in relation to overstory light transmission. Canadian Journal of Forest Research 24:1193-1198.

Author abstract. The potential for use of a partial canopy for controlling growth of Calamagrostis canadensis (Michx.) Beauv., and Epilobium angustifolium L. among regenerating Picea glauca (Moench) Voss saplings was assessed in the understory of 24 established stands in the P. glauca - Viburnum - Rubus pubescens association of the lower boreal cordilleran ecoregion of Alberta. Stand overstories were dominated by Populus tremuloides Michx., P. glauca, or were a mixture of these two species. The composition, basal area, and light transmission of the overstory of each stand were measured. Hardwood-dominated overstories transmitted between 14 and 40% of incoming light while P. glauca canopies transmitted between

5 and 11% of light. Cover and height of C. canadensis and E. angustifolium decreased with decreasing light transmission; at 40% light, both species were greatly reduced compared with open-grown conditions and both were virtually eliminated from stands with less than 10% light. The annual height increment of P. glauca saplings increased from 5 cm at 10% light to 25 cm at 40% light; the latter increment was approximately equal to growth in 100% light conditions. The number of buds, the diameter of the current leader, and the height to diameter ratio of the tree also increased with light transmittance.

◆ **Lieffers, V.J., K.J. Stadt, and S. Navratil. 1996.** Age structure and growth of understory white spruce under aspen. Canadian Journal of Forest Research, 26: 1002-1007.

Author abstract. Juvenile white spruce (Picea glauca (Moench) Voss) under an aspen (Populus tremuloides Michx.) overstory were studied in nine boreal mixedwood stands in west-central Alberta. In each stand, 50 understory white spruce were cut for stem analysis at ground level, 30, 70, 130 cm, and every 100 cm to tree height. In four stands, recruitment of these understory spruce occurred immediately after the disturbance, while in others the recruitment was delayed several decades. The period of recruitment was as short as 15–20 years or continued for decades, producing an uneven-aged understory. Trees initiated on rotten logs had a slightly lower initial annual diameter increment but did not differ in height growth compared with those initiated on normal forest floor. The annual height increment increased as the trees grew in height, presumably as they overtopped successive layers of shading vegetation. When seedlings were less than 30 cm tall they grew less than 10 cm per year, but attained growth rates of 30 cm per year or more when they were taller than 230 cm. Height growth rates for these understory trees were comparable to reported growth rates of white spruce of similar size and age from clearcut area.

◆ **Lloyd, A.H., C.L. Fastie, and H. Eisen. 2007.** Fire and substrate interact to control the northern range limit of black spruce (*Picea mariana*) in Alaska. Can. J. For. Res. 37(12): 2480-2493, 10.1139/X07-092

Author abstract. Black spruce (Picea mariana (Mill.) BSP) is a common treeline species in eastern Canada but rare at treeline in Alaska. We investigated fire and substrate effects on black spruce populations at six sites along a 74 km transect in the Brooks Range, Alaska. Our southern sites, on a surface deglaciated >50 000 years ago, had significantly more acidic soils, more black spruce, and higher seed viability than our northern sites, which were deglaciated approximately 13 000 years ago. Despite similar fire history at five of our six sites, postfire recruitment dynamics varied with surface age. Sexual reproduction was vigorous in both postfire and nonfire years in populations on the older surface. On the younger surface, vigorous sexual reproduction was restricted to postfire decades and clonal reproduction by branch layering predominated in nonfire years. At the northernmost site, which was unburned, black spruce reproduced almost exclusively by layering. The species' northern range limit thus reflects an interaction between fire and substrate: on recently deglaciated surfaces, sexual reproduction is restricted to postfire years. This substrate-induced dependence on fire may restrict the range of black spruce to sites that burn sufficiently often to allow occasional sexual reproduction.

◆ **Lloyd, A.H., A.E. Wilson, C.L. Fastie, and R.M. Landis. 2005.** Population dynamics of black spruce and white spruce near the arctic tree line in the southern Brooks Range, Alaska Can. J. For. Res. 35(9): 2073-2081, 10.1139/x05-119

Author abstract. Black spruce (*Picea mariana* (Mill.) BSP) is the dominant species in interior Alaska but it is largely absent from the arctic tree line. To evaluate the importance of climate and fire as controls over the species distribution, we reconstructed stand history at three sites near its northern limit in Alaska, where it grows with white spruce (*Picea glauca* (Moench) Voss). We developed a matrix model to explore black spruce population dynamics and response to varying fire intervals. All sites burned in the early 1900s. High recruitment of black spruce occurred for <30 years following the fire, but most current black spruce recruitment is clonal and seed viability is low. White spruce recruitment has been consistently high since the fire, and the majority of seedlings in the stands are white spruce. Despite low recruitment, the matrix model suggests that black spruce populations are nearly stable, largely because of low adult mortality rates. Although black spruce recruitment is stimulated by fire, the model indicates that fire intervals <350 years would destabilize the population, primarily because of slow growth and low seed production. Population dynamics of black spruce at its northern limit in Alaska thus appear to reflect an interaction between fire, which determines the temporal pattern of tree recruitment, and climate, which limits tree growth and, presumably, viable seed production.

◆ **Long, J.N. and K. Mock. 2012.** Changing perspectives on regeneration ecology and genetic diversity in western quaking aspen: implications for silviculture. CJFR 42(12): 2011-2021, 10.1139/x2012-143.

Author abstract. A conventional view of regeneration ecology of quaking aspen (*Populus tremuloides* Michx.) in western North American holds that reproduction is strictly vegetative and, except on some marginal sites, only successful following high-severity disturbance. This view has strongly influenced silvicultural treatment of western aspen and has led to low expectations concerning genetic diversity of stands and landscapes. However, recent discoveries are fundamentally altering our understanding of western aspen regeneration ecology and genetics. For example, there are clearly multiple pathways of aspen regeneration and stand development. Research on a variety of fronts indicates that seedling establishment is common enough to be ecologically important and that genetic diversity is substantially greater than previously thought. We review conventional understanding of western aspen and put this into the context of silvicultural practice. We then review recent developments in aspen research and assess the silvicultural implications of these insights.

◆ **Messier, C., Doucet, R., Ruel, J.C., Claveau, Y., Kelly, C., Lechowicz, M.J., 1999.** Functional ecology of advance regeneration in relation to light in boreal forests. Can. J. For. Res.-Rev. Can. Rech. For. 29, 812-823.

Author abstract. This paper reviews aspects of the functional ecology of naturally established tree seedlings in the boreal forests of North America with an emphasis on the relationship between light availability and the growth and survival of shade tolerant conifers up to pole size. Shade tolerant conifer species such as firs and spruces tend to have a lower specific leaf mass, photosynthetic rate at saturation, live crown ratio, STAR (shoot silhouette area to total needle surface area ratio), and root to shoot ratio than the shade intolerant pines. The inability of intolerant species such as the pines and aspen to survive in shade appears to be mainly the result of characteristics at the. shoot, crown, and whole-tree levels and not at the leaf level. Although firs and spruces frequently coexist in shaded understories, they do not have identical growth patterns and crown architectures. We propose a simple framework based on the maximum height that different tree species can sustain in shade, which may help managers determine the timing of partial or complete harvests. Consideration of these functional aspects of regeneration is important to the understanding of boreal forest dynamics and can be useful to forest managers seeking to develop or assess novel silvicultural systems.

◆ **Nilsson, Marie-Charlotte, and David A. Wardle. 2005**. Understory vegetation as a forest ecosystem driver: evidence from the northern Swedish boreal forest. Frontiers in Ecology and Environment 3(8): 421–428.

Author abstract. Vegetation research in boreal forests has tended to focus on the tree component, while little attention has been paid to understory components such as dwarf shrubs, mosses, and reindeer lichens. However, the productivity of understory vegetation is probably comparable to that of the trees. We review recent research in the boreal forest of northern Sweden to highlight the ecological importance of understory vegetation, both in the short term by influencing tree seedling regeneration, and in the longer term by affecting belowground processes such as decomposition, nutrient flow, and buildup of soil nutrients. Wildfire resulting from lightning strike is a primary determinant of understory vegetation, and as such is a major driver of forest community and ecosystem properties. Forest management practices that alter the fire regime and the composition of understory vegetation may have long-term consequences for both conservation goals and commercial forest productivity.

◆ **Paquin, R. H.A. Margolis, R. Doucet, and M.R. Coyea. 1999**. Comparison of growth and physiology of layers and naturally established seedlings of black spruce in a boreal cutover in Quebec. Canadian Journal of Forest Research, 1999, 29(1): 1-8, 10.1139/x98-171

Author abstract. Growth and physiology of layers versus naturally established seedlings of boreal black spruce (*Picea mariana* (Mill.) BSP) were compared 15 years after a cutover in Quebec. During the first 8 years, height growth of seedlings was greater than that of layers, averaging 10.4 and 7.0 cm/year, respectively. For the last 5 years, annual height growth of layers and seedlings did not differ (25 cm/year; $p > 0.05$). Over the entire 15-year period, total height growth of seedlings (251 cm) was greater than that of layers (220 cm), although total height did not differ ($p > 0.05$) over the last 6 years. During the 15th growing season, there were no differences ($p > 0.05$) for predawn shoot water potential, stomatal conductance, net photosynthesis, intercellular to ambient CO_2 ratio, water use efficiency, and hydraulic conductance between layers and seedlings. For diurnal shoot water potential, seedlings showed slightly less stress than layers on two of the four sampling dates. Thus, in the first few years following the cutover, the slower growth observed for layers indicated that they had a longer acclimation period following the cutover. Afterwards, similar height growth, total height, and physiological characteristics of the two regeneration types indicated that layers can perform as well as naturally established seedlings.

◆ **Roessler, J.S. 1997.** Disturbance history in the Tanana River basin of Alaska: Management implications. Unpubl. M.S. Thesis, Univ. Alaska, Fairbanks, 220 p.

Author abstract. The forests of the Tanana River Basin in Interior Alaska have a history of disturbance. Four issues reflecting forest disturbance. important to include in current management strategies for these lands were researched: (1) disturbance history of the Tanana Valley; (2) Alaska Interagency Fire Management Plan: a case study; (3) prescribed natural fire in Alaska: possibilities and complexities; and (4) past use of prescribed fire in white spruce: a summary with particular reference to Alaska. Through researching historical archives, conducting field site visits, interviewing land and fire managers and reviewing current planning documents. I reached four major conclusions: (1) there is lack of use of historical facts regarding human-induced changes on the landscapes; (2) past involvement of public stake-holders in fire planning in Alaska was inadequate; (3) the Alaska Interagency Fire Management Plans need to identify scientific prescription parameters which address specific land management objectives; and (4) management-ignited prescribed fire must become a more common prescription after harvesting of white spruce.

◆ **Rossi, S., Tremblay, M.J., Morin, H., Savard, G., 2009**. Growth and productivity of black spruce in even- and uneven-aged stands at the limit of the closed boreal forest. For. Ecol. Manage. 258, 2153-2161.

Author abstract. The increasing commercial interest and advancing exploitation of new remote territories of the boreal forest require deeper knowledge of the productivity of these ecosystems. Canadian boreal forests are commonly assumed to be evenly aged, but recent studies show that frequent small-scale disturbances can lead to uneven-aged class distributions. However, how age distribution affects tree growth and stand productivity at high latitudes remains an unanswered question. Dynamics of tree growth in even- and uneven-aged stands at the limit of the closed black spruce (Picea mariana) forest in Quebec (Canada) were assessed on 18 plots with ages ranging from 77 to 340 years. Height, diameter and age of all trees were measured Stem analysis was performed on the 10 dominant trees of each plot by measuring tree-ring widths on discs collected each meter from the stem, and the growth dynamics in height, diameter and volume were estimated according to tree age Although growth followed a sigmoid pattern with similar shapes and asymptotes in even- and uneven-aged stands, trees in the latter showed curves more flattened and with increases delayed in time. Growth rates in even-aged plots were at least twice those of uneven-aged plots The vigorous growth rates occurred earlier in trees of even-aged plots with a culmination of the mean annual increment in height, diameter and volume estimated at 40-80 years, 90-110 years earlier than in uneven-aged plots. Stand volume ranged between 30 and 238 m(3) ha(-1) with 75% of stands showing values lower than 120 m(3) ha(-1) and higher volumes Occurring at greater dominant heights and stand densities. Results demonstrated the different growth dynamics of black spruce in single- and multi-cohort stands and suggested the need for information on the stand structure when estimating the effective or potential growth performance for forest management of this species.

◆ **Schulz, B. 1999.** Competitive effects of residual understory an dearly successional vegetation on initial stocking following ecosystem disturbance. Pp. 32-42 in: Proc. of the

Alaska Reforestation Council April 29, 1999 Workshop. Anchorage, AK. Univ. of Alaska Fairbanks Agric. & For. Exp. Sta. Misc. Publ. 99-8. 85 pp.

Author abstract. An understanding of basic disturbance ecology must be applied in determining the most appropriate management action to achieve landowner objectives in restoring disturbed ecosystems. Wildfires, spruce beetle (*Dendroctonus rufipennis* Kirby) epidemics, wind, animals, and timber harvests cause major forest disturbance in northern Alaska. Restoration of disturbed forests depends on site potential, type and intensity of disturbances, surviving species, and seedbed conditions. In the absence of natural regeneration, site preparation and artificial reforestation are the only alternatives for restoring forest communities. Recommendations for Lutz (*Picea* x*lutzii* Little) and white spruce (*Picea glauca* Moench Voss) regeneration following spruce beetle outbreaks are given.

◆ **Shaw, J.D., E.C. Packee, and C-L. Ping. 2001**. Growth of balsam poplar and black cottonwood in Alaska in relation to landform and soil. Canadian Journal of Forest Research 31(10): 1793-1804, 10.1139/x01-119

Author abstract. While constructing site index curves for balsam poplar (*Populus balsamifera* L.) and western black cottonwood (*Populus trichocarpa* Torr. & A. Gray) for interior and southcentral Alaska, we found variations in growth patterns that appeared to be related to landform and soil properties. We characterized soils for 42 of 65 site index plots in an attempt to explain site productivity variation. We found significant negative correlations between site index and elevation. Region, landform, and floodplain characteristics (especially sediment deposition) significantly affected poplar growth rate and soil development patterns. Nutrient availability and recycling appear to be mediated by flooding through scouring or burial of surface organic layers. Soil pH patterns related to O-horizon development and salt crust formation and dissolution described previously for the Tanana River floodplain do not hold for all floodplains in Alaska. At similar latitudes and elevations, upland locations may have higher site indices than frequently sedimented floodplain locations because upland soil development is relatively uninterrupted. Floodplain locations experiencing little or no sediment accumulation after establishment of poplar stands tend to have higher site indices than those experiencing frequent sediment accumulation. At some floodplain locations, site index was positively correlated with rooting depth.

◆ **Sirois, L. 2000.** Spatiotemporal variation in black spruce cone and seed crops along a boreal forest - tree line transect. Canadian Journal of Forest Research, 2000, 30(6): 900-909, 10.1139/x00-015

Author abstract. To assess the relationship between the regenerative potential of black spruce (*Picea mariana* (Mill.) BSP) and the latitudinal and thermal gradients, the cone crop was monitored in the same selection of trees during the 1989-1995 period in the northern boreal forest (sites A, n = 49, and B, n = 48), in the southern forest-tundra transition zone (site C, n = 35), and at the tree line (site D, n = 21). The size of the cone crop, the amount of seeds extracted per cone, along with the percentages of filled seed and germination were measured on each tree. There was no south to north trend associated with the cone crop. The cone crop at tree line was not significantly lower than in either of the southerly sites in six of the seven observed years. The

number of seeds extracted per cone, the percentage of filled seeds, and the germination of filled seeds showed significant decrease northward according to year. Although there was no significant relationship between temperature and the cone production over the study area, the percentages of filled seeds and germination were significantly ($0.51 \geq r^2 \geq 0.44$; $p < 0.001$) associated with the regional variation in heat sum.

◆ **Taylor, A.R. and H.Y.H Chen. 2011.** Multiple successional pathways of boreal forest stands in central Canada. Ecography 34, 208-219.

Author abstract. Predicting forest composition change through time is a key challenge in forest management. While multiple successional pathways are theorized for boreal forests, empirical evidence is lacking, largely because succession has been inferred from chronosequence and dendrochronological methods. We tested the hypotheses that stands of compositionally similar overstory may follow multiple successional pathways depending on time since last stand-replacing fire (TSF), edaphic conditions, and presence of intermediate disturbances. We used repeated measurements from combining sequential aerial photography and ground surveys for 361 boreal stands in central Canada. Stands were measured in 8-15 yr intervals over a similar to 60 yr period, covering a wide range of initial stand conditions. Multinomial logistic regression was used to analyze stand type transitions. With increasing TSF, stands dominated by shade-intolerant Pinus banksiana, Populus sp., and Betula papyrifera demonstrated multiple pathways to stands dominated by shade-tolerant Picea sp., Abies balsamea, and Thuja occidentalis. Their pathways seemed largely explained by neighborhood effects. Succession of stands dominated by shade-tolerant species, with an exception of stands dominated by Picea sp., was not related to TSF, but rather dependent on edaphic conditions and presence of intermediate disturbances. Varying edaphic conditions caused divergent pathways with resource limited sites being dominated by nutrient-poor tolerant species, and richer sites permitting invasion of early successional species and promoting species mixtures during succession. Intermediate disturbances promoted deciduous persistence and species diversity in A. balsamea and mixed-conifer stands, but no evidence was detected to support "disturbance accelerated succession". Our results demonstrate that in the prolonged absence of stand-replacing disturbance boreal forest stands undergo multiple succession pathways. These pathways are regulated by neighborhood effects, resource availability, and presence of intermediate disturbance, but the relative importance of these regulators depends on initial stand type. The observed divergence of successional pathways supports the resource-ratio hypothesis of plant succession.

◆ **Taylor, R. F. 1934.** A preliminary study of natural reproduction and timber growth of the Kenai Division, Chugach National Forest. U.S. Dept. of Agriculture, Forest Service, Chugach National Forest; Washington, D.C. : U.S. G.P.O. Special Studies – Kenai Division. 10 pp.

Compiler abstract. This 1934 paper describes vegetation on the Kenai Peninsula, primarily in the coastal forest. There is a short description of the interior forest type.

◆ **Towill, W.D. 2001.** Silvicultural systems: Getting to a desired future forest. Pp.51-54 in Proc. for the Ecology and management of white birch workshop. Sept. 21-22, 1999. Ontario Ministry of Natural Resources, Northeast Science & Technology, Ontario Government Complex, PO Bag 3020, S. Porcupine, ON. 67 pp.

Compiler abstract. The author summarizes key silvicultural factors and considerations for paper birch silviculture systems in pure, single-storied stands; mixed, single-storied stands of white birch and jack pine, and uneven-aged stands of white spruce and white birch. Factors addressed include climate, soil-site relationships, light requirements, fire tolerance, seed and vegetation reproduction, insect and disease issues, and silvicultural challenges in boreal forests.

◆ **Viereck, L.A., C.T. Dyrness, and M.J. Foote. 1993.** An overview of the vegetation and soils of the floodplain ecosystems of the Tanana River, interior Alaska. Canadian Journal of Forest Research, 1993, 23(5): 889-898, 10.1139/x93-117

Author abstract. The soils and vegetation of 12 stages of forest succession on the floodplain of the Tanana River are described. Succession begins with the invasion of newly deposited alluvium by willows (*Salix* spp.) and develops through a willow–alder (*Alnus tenuifolia* Nutt.) stage to forest stands of balsam poplar (*Populus balsamifera* L.), followed by white spruce (*Picea glauca* (Moench) Voss), and finally black spruce (*Picea mariana* (Mill.) B.S.P.). The principal changes in substrate characteristics during the successional sequence are (*i*) change from sand to silt loam, (*ii*) increase in terrace height and distance from the water table, (*iii*) development of a forest floor, first of leaf litter and then live and dead feather mosses, (*iv*) burial of organic layers by flooding, and (*v*) the development of permafrost as soils are insulated by a thick organic layer. Soils and vegetation of six stands occurring in three successional stages used in the salt-affected soils study are described in detail: open willow stands (stage III), balsam poplar–alder stands (stage VI), and a mature white spruce stand (stage VIII). There is a general progression of plant species resulting from the modification of the environment by the developing vegetation and changes in soil characteristics. Life history and stochastic events are important in the early stages of succession, and biological controls such as facilitation and competition become more important in middle and late stages of succession.

◆ **Viglas, J. N., C. D. Brown, and J. F. Johnstone. 2013.** Age and size effects on seed productivity of northern black spruce. Canadian Journal of Forest Research 43:534–543.

Author abstract. Slow-growing conifers of the northern boreal forest may require several decades to reach reproductive maturity, making them vulnerable to increases in disturbance frequency. Here, we examine the relationship between stand age and seed productivity of black spruce (*Picea mariana* (Mill.) Britton, Sterns & Poggenb.) in Yukon Territory and Alaska. Black spruce trees were aged and surveyed for cone production and seed viability across 30 even-aged stands ranging from 12 to 197 years old. Logistic regression indicated that individual trees had a ~50% probability of producing cones by age 30 years, which increased to 90% by age 100 years. Cone and seed production increased steadily with age or basal area at both the tree and stand level, with no evidence of declining seed production in trees older than 150 years. Using published seed:seedling ratios, we estimated that postfire recruitment will be limited by seed availability in stands for up to 50 years (on high-quality seedbeds) to 150 years (low-quality seedbeds) after fire. By quantifying these age and seed productivity relationships, we can improve our ability to predict the sensitivity of conifer seed production to a range of disturbance frequencies and thus anticipate changes in boreal forest resilience to altered fire regime.

◆ **Vogt, S.L. 2002.** A characterization of mixed forest stands in the Tanana Valley, Alaska. Unpubl. Thesis. Univ. of Alaska Fairbanks, Agric. and For. Exp. Station. 153 pp.

Author abstract. The objective of this thesis is to define the composition, age structure, volume ranges, and community types present in the Tanana Valley mixed stands. Sixty-six permanent sample plots were established in 22 forest stands located throughout the Valley. Plots were at least 100 feet from a road. Total height, crown height, diameter breast height were measured and health and vigor were assessed for 5,415 trees. Five tree species and 57 herb and shrub species were found. White spruce, birch, and aspen numbers are generally less in mixed stands than predicted for pure stands. Stand density index values, a method of assessing species' use of growing space, ranged from 61 to 422 stems per acre with a mean of 269. Existing individual tree volume tables need revision to avoid negative values for small trees. Existing site index curves for pure stands of lnterior species are inadequate for comparing to mixed stands.

◆ **Wilmking, M. 2003.** The treeline ecotone in interior Alaska : from theory to planning and the ecology in between. Unpubl.. PhD thesis. Univ. of Alaska Fairbanks. 130 pp.

Author abstract. Treelines have been the focus of intense research for nearly a hundred years, also because they represent one of the most visible boundaries between two ecological systems. In recent years however, treelines have been studied, because changes in forest ecosystems due to global change, e.g. treeline movement, are expected to manifest first in these areas. This dissertation focuses on the elevational and latitudinal treelines bordering the boreal forest of interior Alaska. After development of a conceptional model of ecotones as three-dimensional spaces between ecosystems, we offer a historical perspective on treeline research and its broader impact in the Brooks Range, Alaska. Dendrochronological analysis of >1500 white spruce (Picea glauca) at 13 treeline sites in Alaska revealed both positive and negative growth responses to climate warming, challenging the widespread assumption that northern treeline trees grow better with warming climate. Hot Julys decreased growth of 4̃0% of white spruce at treeline in Alaska, whereas warm springs enhanced growth of others. Growth increases and decreases appear at temperature thresholds, which have occurred more frequently in the late 20th century. Based on these relationships between tree-growth and climate as well as using landscape characteristics, we modeled future tree-growth and distribution in two National Parks in Alaska and extrapolated the results into the 21st century using climate scenarios from five General Circulation Models. In Gates of the Arctic National Park our results indicate enhanced growth at low elevation, whereas other areas will see changes in forest structure (dieback of tree-islands, infilling of existing stands). In Denali National Park, our results indicate possible dieback of white spruce at low elevations and treeline advance and infilling at high elevations. This will affect the road corridor with a forest increase of about 50% along the road, which will decrease the possibility for wildlife viewing. Surprisingly, aspect did not affect tree growth - climate relationships. Without accounting for opposite growth responses under warming conditions, temperature thresholds, as well as meso-scale changes in forest distribution, climate reconstructions based on ring-width will miscalibrate past climate, and biogeochemical and dynamic vegetation models will overestimate carbon uptake and treeline advance under future warming scenarios.

◆ **Winslow, S.E. 2008.** Tree growth history, climate sensitivity, and growth potential of black and white spruce along the middle Kuskokwim River, Alaska . Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 68 pp.

Author abstract. People living in the Kuskokwim River Basin often rely on wood to heat their homes and are considering wood-fueled energy generation. To help inform community decisions we examined the growth history, climate sensitivity and growth potential of local tree species. We compared ring-width growth of 188 white spruce (Picea glauca (Moench) Voss) and 77 black spruce and black spruce (Picea mariana (Mill.) B.S.P.) trees sampled along 370 km of the Kuskokwim River, Alaska to mean monthly temperatures (MMT) and total monthly precipitation (TMP) at McGrath. White spruce trees were either significantly negatively correlated (r = -0.62) with MMT of August and June (-2) (two years prior to ring formation) or positively correlated (r=0.60) with MMT of April (-2) and November (-2). Black spruce trees were either negatively correlated (r = -0.64) with a warmth-dryness index composed of August and June (-1) MMT minus TMP of August and June (-2) or positively correlated (r = 0.60) with April (-1) and June (-1) MMTs. Negative growth responders predominate in eastern (warmer and dryer) locations while positive responders predominate in western (cooler, wetter) locations. The negative growth trend in interior white and black spruce decreases the potential for wood-fueled energy generation.

◆ **Wurtz, T.L. 1988.** Effects of the microsite on the growth of planted white spruce seedlings. Unpubl. PhD Thesis. Univ. of Oregon. 200 pp.

Author abstract. Use of forest resources in interior Alaska is increasing, yet little information is available on the regeneration requirements of the main commercial species of this region, white spruce (*Picea glauca* [Moench] Voss). In particular, little is known about factors affecting the growth of planted seedlings. Portions of three floodplain sites were clearcut or shelterwood cut, and were subjected to one of four site preparation treatments. The four treatments represented a range in disturbance level from light (mechanical scarification) to severe (broadcast burning). White spruce seedlings were planted in the forest cutovers. Four features of each microsite were described: (1) microtopography; (2) associated vegetation; (3) light environment; and (4) soil profile. Seedling growth was monitored for three years. Seedling growth was unrelated to either the microtopography or the light environment of the microsite. Some measures of seedling growth were related to some species of associated vegetation. The microsite feature most consistently related to seedling growth was the mineral soil content of the 20 cm soil profile. This variable is a function of site age and the level to which organic soil has been removed from the profile by site preparation. Microsites in the severely burned area had the most mineral soil and the best seedling growth of any treatment area. Work by Dyrness, Viereck, Foote and Zasada (1988) on the same sites documented dramatic increases in soil temperature following severe broadcast burning. Together, these results suggest that soil temperature is the critical factor influencing establishment and early seedling growth on floodplain sites. The mineral soil content of the profile appears to be an effective, easily-measured indicator of soil temperature. The measurement of this microsite variable may help silviculturists choose and assess site preparation methods, and may help tree planters choose individual planting spots.

◆ **Yarie, J. 1993.** Effects of selected forest management practices on environmental parameters related to successional development on the Tanana River floodplain, interior Alaska. Canadian Journal of Forest Research, 1993, 23(5): 1001-1014, 10.1139/x93-128

Author abstract. Two mature floodplain white spruce (*Picea glauca* (Moench) Voss) ecosystems (stage VIII) located on islands in the Tanana River, approximately 20 km southwest of Fairbanks, Alaska, were clear-cut during the winter of 1985–1986 to quantify the effects of clear-cutting on selected environmental characteristics. Clearings in earlier successional stages (poplar–alder (*Populus–Alnus*), stage V; and open willow (*Salix*), stage III) were used to contrast the environmental parameters with the earlier stages found in the primary successional sequence. After clear-cutting, total radiation at the soil surface increased to early successional stage III levels. Potential evaporation from the soil surface increased 5-fold as a result of clearing in the stage VIII sites and was substantially greater than that found in the stage III sites by other researchers. Clearing had relatively little effect on air temperature. The concentration of P and K was significantly lower in the forest floor of both clearcuts, and the concentration of C was significantly higher at VIII-A-T (stage VIII–site A–treated (cleared) plot) when compared with the control stands. There was a decrease in total forest floor biomass at both clear-cut plots. Organic matter, total N, available NH_4 and P, and extractable Mg and K all decreased after cutting, whereas pH increased. Decomposition of spruce foliage on the forest floor surface was slower in the clearcuts. Nitrogen immobilization occurred during the first 2 years of decomposition. During the third year it appeared that some mineralization was beginning to occur but the levels were very low, averaging only 3 mg N per bag in the clear-cut areas. Plant growth analysis indicated that growth was limited by high mineral soil salt content in the early successional stages (III) and that this limitation was species specific. Balsam poplar (*Populus balsamifera* L.) appears to be more tolerant of the high cation content of the stage III sites compared with trembling aspen (*Populus tremuloides* Michx.). By the time successional development has progressed to stage V, the soil has been sufficiently augmented by the inclusion of organic matter from the developing vegetation and the fixation of N by alder to result in higher seedling growth rates in the cleared areas.

◆ **Young, B. D. 2012.** Diversity in the boreal forest of Alaska: distribution and impacts on ecosystem services. Unpubl. PhD thesis. Univ. of Alaska Fairbanks. 261 pp.

Author abstract. Within the forest management community, diversity is often considered as simply a list of species present at a location. In this study, diversity refers to species richness and evenness and takes into account vegetation structure (i.e. size, density, and complexity) that characterize a given forest ecosystem and can typically be measured using existing forest inventories. Within interior Alaska the largest forest inventories are the Cooperative Alaska Forest Inventory and the Wainwright Forest Inventory. The limited distribution of these inventories constrains the predictions that can be made. In this thesis, I examine forest diversity in three distinct frameworks; Recruitment, Patterns, and Production. In Chapter 1, I explore forest management decisions that may shape forest diversity and its role and impacts in the boreal forest. In Chapter 2, I evaluate and map the relationships between recruitment and species and tree size diversity using a geospatial approach. My results show a consistent positive relationship between recruitment and species diversity and a general negative relationship between recruitment and tree size diversity, indicating a tradeoff between species diversity and tree size diversity in their effects on recruitment. In Chapter 3, I modeled and mapped current and possible future forest diversity patterns within the boreal forest of Alaska using machine learning. The results indicate that the geographic patterns of the two diversity measures differ greatly for both current conditions and future scenarios and that these are more strongly influenced by human impacts than by ecological factors. In Chapter 4, I developed a method for mapping and predicting forest biomass for the boreal forest of interior Alaska using three different machine-learning techniques. I developed first time high resolution prediction maps at a 1 km^2 pixel size for aboveground woody biomass. My results indicate that the geographic patterns of biomass are strongly influenced by the tree size class diversity of a given stand. Finally, in Chapter 5, I argue that the methods and results developed for this dissertation can aid in our understanding of forest ecology and forest management decisions within the boreal region.

◆ **Young, B., J.J. Liang, and F.S. Chapin. 2011.** Effects of species and tree size diversity on recruitment in the Alaskan boreal forest: A geospatial approach. Forest Ecology and Management 262:1608-1617.

Author abstract. This study empirically evaluates and maps the relationships between recruitment and species and tree size diversity, as measured with the Shannon's index, within mixed poplar/birch and mixed spruce stands across the boreal forest of Alaska. Data were collected from 438 permanent sample plots re-measured at a 5-year interval. Significant explanatory factors of recruitment, including species and tree size diversity were first identified using hierarchical partitioning. The effects of tree diversity on recruitment were then studied using generalized linear models and universal kriging to account for non-spatial factors and for spatial autocorrelation. We found a consistent positive relationship between recruitment and species diversity and a general negative relationship between recruitment and tree size diversity, indicating a tradeoff between species diversity and tree size diversity in affecting recruitment. These relationships however were not uniform across the landscape, presumably because they were subject to strong spatial autocorrelation attributable to natural disturbances and environmental stressors. In general, diversity had least effect on recruitment in stressful environments where stress, rather than competition, most likely governed recruitment.

◆ **Youngblood, A., M. Newton, and E. Cole. 1999.** Adaptability of Spruce Seedlings for forest restoration in interior and southcentral Alaska. pp. 51-56 in: Proc. of the Alaska Reforestation Council April 29, 1999 Workshop. Anchorage, AK. Univ. of Alaska Fairbanks Agric. & For. Exp. Sta. Misc. Publ. 99-8. 85 pp.

Author abstract. Changes in forest structure and composition, fuel accumulations, and lack of regeneration from past timber harvests and spruce beetle-caused mortality are likely to challenge forest managers and landowners in south-central Alaska for the next decade. The need for site-specific prescriptions to restore important white spruce ecosystems is critical. With initial Funding from the Alaska Science and Technology Foundation, we began work in 1995 to link the role of past disturbance, competing vegetation, site preparation, container seedling production, and seedling physiology to understand white spruce reforestation options. Field installations were established in the Tanana River uplands west of Fairbanks, the Matanuska-Susitna Valley, two locations on the Kenai Peninsula, and the Copper River Basin. At each location, sites representing relatively old harvesting activity and recent clearing were selected for testing white spruce seedling survival and growth of five stock types in combination with blade scarification, herbicide, and no site preparation treatments. Measures of plant competition include cover and overtopping. Preliminary results are confined to initial mortality and the first two years growth.

Initial survival was height for all site preparation treatments and stock types at four of the five locations. After two growing seasons seedling heights were strongly influenced by nursery performance. Herbicides and scarification removed most of the competing vegetation, but scarified sites were warmer than herbicide and untreated sites during the growing season. Differences among site treatments and stock types are expect to increase in coming years.

◆ **Youngblood, A. 1995.** Development patterns in young conifer-hardwood forests of interior Alaska. Journal of Vegetation Science, 6: 229–236.

Author abstract. The age structure and growth patterns of 53 young conifer-hardwood stands on upland, south-facing sites of interior Alaska were analyzed to determine the length of time for stand establishment after disturbance, the composition of early-successional stands compared to existing stands, and the potential for late-successional stands dominated by conifers. Mixed stands of *Picea glauca*, *Populus tremuloides* and *Betula papyrifera* represented five plant community types and developed as single cohorts after stand-replacement fires. In the *Populus tremuloides/Arctostaphylos uva-ursi* and *Populus tremuloides/Shepherdia canadensis* community types, hardwoods established rapidly and *Picea glauca* established slowly. In contrast, stands in the *Betula papyrifera-Populus tremuloides/Viburnum edule*, *Betula papyrifera-Populus tremuloides/Alnus crispa*, and *Picea glauca-Betula papyrifera/Hylocomium splendens* community types generally developed as a result of rapid, concurrent establishment of conifers and hardwoods. These single-cohort, mixed species development patterns are not consistent with continual establishment of conifers and are likely the result of unique life-history traits and frequent stand-replacement fires.

◆ **Zasada, J.C. 2001.** Some considerations for the natural regeneration of paper birch. Pp.45-50 in Proc. for the Ecology and management of white birch workshop. Sept. 21-22, 1999. Ontario Ministry of Natural Resources, Northeast Science & Technology, Ontario Government Complex, PO Bag 3020, S. Porcupine, ON. 67 pp.

Author abstract. Natural regeneration of paper birch (*Betula papyrifera Marsh.*), as with most north temperate and boreal hardwood species, can be from vegetative reproduction or from seed. This brief discussion summarizes some aspects of these processes that seem to be particularly important when prescribing silvicultural practices that will favour natural regeneration. The discussion will be centered around the conceptual models for vegetative reproduction (Fig. 1) and regeneration from seed (Fig. 2). A more detailed description of these conceptual models with reference to boreal trees is available in Zasada *et al.* (1992). Most of the thinking behind these models comes from Harper's book on Population Biology of Plants (1977). The information summarized below is based on my experience and the findings of the publications listed in the References [of the Conference Proceedings].

◆ **Zasada, J.C. 1988.** Embryo growth in Alaskan white spruce seeds. Canadian Journal of Forest Research, 1988, 18(1): 64-67, 10.1139/x88-010.

Author abstract. Embryo development in white spruce seeds was studied in five stands in interior Alaska. Cones and seeds were collected at 10- to 14-day intervals starting in mid-July and continuing until just before seed dispersal began. Significant differences were found in embryo development between stands, between trees within stands, and between cones within trees. The four stands at lower elevations produced seeds that had embryos filling 95% or more of the embryo cavity; this percentage was significantly higher than the highest elevation stand where embryos filled about 75% of the embryo cavity at the end of the growing season. Relative cotyledon length was generally greater than 25% in the lower elevation stands and slightly less than 20% in the high elevation stand. Although seed collection can be started when embryos fill 75% of the embryo cavity, the results of this and other studies suggest that collecting seeds when embryos are more mature will result in better quality seeds. Air and soil temperatures and soil moisture levels associated with embryo development are presented.

◆ **Zasada, J.C., 1986**. Natural regeneration of trees and tall shrubs on forest sites in interior Alaska, in: Van Cleve, K., Chapin III, F.S., Flanagan, P.W., Viereck, L.A., Dyrness, C.T. (eds.), Forest Ecosystems in the Alaskan Taiga: A Synthesis of Structure and Function. Springer-Verlag, New York, New York, USA, pp. 44-73.

Author abstract. The forests of interior Alaska are used for a variety of consumptive and nonconsumptive uses. Multiple- or single-use management of these forests requires a working knowledge of how these uses affect the sustained yield or availability of a particular product or use. Many biotic and abiotic environmental variables as well as socio economic concerns must be considered in developing these management alternatives. A knowledge of the reproductive biology and ecology is a necessary component in this decision-making process. Sustained production has, as an absolute requirement, the ability of the land manager to predict or determine the consequences of any disturbance in terms of the species composition and density; a detailed knowledge of the reproductive process is one important component necessary for developing this predictive capability. In many cases, it is possible for the land manager to create conditions that are more or less favorable for a selected species or group of species, and thus to exercise some control over the natural developmental process and pattern of forest types and distribution of trees within a type.

◆ **Zasada, J.C. 1984.** Site classification and regeneration practices on floodplain sites in interior Alaska . pp. 35-37 in: Pacific Northwest forest and range station general technical report PNW-177. M. Murray, ed. 56 pp.

Introduction. The floodplains of Alaska's rivers are some of the most productive forest sites in the state. Historically these forests, in particular white spruce *(Picea glauca),* were heavily utilized during the gold rush and settlement period of the early 1900s. As transportation of building and heating materials from outside of Alaska became more efficient, local forest utilization decreased. Present utilization is insignificant except near villages where forests are the only readily accessible source of wood. There is high potential to increase utilization of these stands. The impetus for this increase appears to stem from political and economic interest. Management experience and research information that can be applied to management of floodplain sites is limited. The most detailed research on any aspect of management on northern river floodplains (north of 60° N latitude) was reported by Gardner (1983) for the Liard and Meister rivers in southern Yukon. Ganns (1977) reported on regeneration studies on Tanana

River (Alaska) sites. Experience gained from management on uplands in Alaska .provides some insight into management alternatives for flood plains. However, ecological conditions on these two physiographically distinct areas are different in several important ways, and practices may not be directly transferable from one type of area to the other (Zasada et al. 1977).

In contrast to the lack of management experience is the availability of a relatively large body of basic ecological information for flood plain sites (Viereck 1970a, 1970b; Van Cleve et al. 1971, 1980; Van Cleve and Viereck 1972, 1980; Juday and Zasada 1984). These studies provide valuable information on site development and forest succession. However, they do not deal with secondary forest succession following such disturbances as fire and harvesting.
The purpose of this paper is to consider factors that affect white spruce regeneration on flood plains. To do this, we first need to consider, briefly, the development of forests on these sites - how white spruce stands originate and their fate in the absence of disturbance. In the second part of this paper, regeneration alternatives will be discussed using the Willow Island research project as an example. This project is primarily concerned with regeneration options following harvesting, but white spruce stand and site development have also been examined in some detail (Juday and Zasada 1984).

◆ **Zasada, J.C. 1978.** Case history of an excellent white spruce cone and seed crop in interior Alaska : cone and seed production, germination, and seedling survival . USDA Forest Service Gen. Tech. Rep. PNW-65. 53 pp.

Author abstract. The development of the excellent crop of 1970 is described until 1975 in 29 stands and a transect along the Richardson Highway. Detailed observations of seedlings were made in a small forest opening of the Bonanza Creek Experimental Forest, and comparative data are given for paper birch (Betula papyrifera) in the same stand. Management implications are discussed.

◆ **Zasada, J.C., and G.A. Schier. 1973.** Aspen root suckering in Alaska: effect of clone, collection date, and temperature . Northwest science, v. 47, no. 2, (May 1973), pp. 100-104.

Author abstract. Many of the aspen (Populus tremuloides Michx.) stands in Alaska originated from root suckers after the parent stands were destroyed by fire (Lutz, 1956; Gregory and Haack, 1965). Although there has been extensive research in other parts of the species range on the capacity for aspen to sucker, there has been no research conducted on Alaskan genotypes. To obtain this basic information, initial sucker development on excised roots from three Alaskan clones as affected by dare of collection, clone, and temperature was examined.

◆ **Zasada, J.C., T.L. Sharik and M. Nygren. 1993**. The reproductive process in boreal forest trees. Pages 85-125 in H.H. Shugart, R. Leemans, and G.B. Bonan, eds. A systems analysis of the boreal forest. Cambridge University Press, Cambridge, England.

Author abstract. The boreal forests of the world, geographically situated to the south of the Arctic and generally north of latitude 50 degrees, are considered to be one of the earth's most significant terrestrial ecosystems in terms of their potential for interaction with other global scale systems, such as climate and anthropogenic activity. This book, developed by an international panel of ecologists, provides a synthesis of the important patterns and processes which occur in boreal forests and reviews the principal mechanisms which control the forests' pattern in space and time. The effects of cold temperatures, soil ice, insects, plant competition, wildfires and climatic change on the boreal forests are discussed as a basis for the development of the first global scale computer model of the dynamical change of a biome, able to project the change of the boreal forest over timescales of decades to millennia, and over the global extent of this forest.

Section 3

REFORESTATION METHODS, RESULTS, AND STOCKING STANDARDS

SUMMARY

Doug Hanson, Alaska Department of Natural Resources, Division of Forestry
Will Putman, Tanana Chiefs Conference

In Regions II and III reforestation methods commonly fall into categories of regeneration from seed or regeneration by vegetative sprouting. These methods can be further divided into natural and artificial reforestation methods. Literature cited below provides a variety of references devoted to these topics as well as surveys to document reforestation efforts. Many references are presented in the context of reforesting following harvesting for fuel or timber, but some sources specifically refer to reforesting following other disturbances, particularly the bark beetle infestations that have occurred in recent decades in Region II. Most references are from Alaskan sources, but some rely on research or experiences observed elsewhere in the boreal forest, particularly Canada. One source summarizes reforestation information in the context of FRPA in an earlier iteration of this process (TCC and DOF 1989).

There are numerous references in Section 2, Silvics, which have direct relevance to reforestation options through descriptions of seeding, growth characteristics, and conditions required for seedling establishment. These characteristics include the sporadic nature of white spruce seed crops, the importance of mineral soil seedbeds in white spruce and hardwood regeneration by seed, and the ability for hardwood species to regenerate vegetatively. In addition, many of the references in Section 4, Site Preparation, Competition Control, and Soils, are relevant to this Section on Reforestation Methods due to the difficulty of separating subjects like site preparation and competition control from the subject of reforestation methods. Many of the references in Section 5, Fire and Regeneration, are also relevant to discussions of reforestation methods.

The historical commercial importance of white spruce for both timber and fuel has made it the subject of much of the available literature in the past for Regions II and III. White spruce regenerates only from seed, and seed zones and transfer guidelines have been developed for Alaska (Alden 1991) to maintain genetic identity and productivity of future forests in Alaska. A number of sources address the problems of vegetative competition with white spruce regeneration, particularly that posed by *Calamagrostis Canadensis* (Cole et al. 2003, Graham and Wurtz 2003, Jandreau and Arians 2006, Newton 1996, Wahrenbrock 2014). Options for natural regeneration of white spruce generally involve the presence of mature residual trees as a seed source (Martin-DeMoor et al. 2010), including shelterwood systems, which have been demonstrated to be effective in studies near Fairbanks, especially when accompanied with scarification (Wurtz and Zasada 2001, Youngblood 1990). Delayed regeneration of white spruce after fire, especially in mixed species stands, has been shown to be an important factor in stand development (Peters et al. 2006).

Planting of nursery produced white spruce seedlings has commonly been used, and is the recommended technique by some sources (Maisch et al. 2001). Graham and Wurtz (2003) tested a number of seedling stock types with variable results, indicating that planting performance depends on a number of factors, including stock type, competing vegetation and microsite. One study near Fairbanks suggests that white spruce can be successfully regenerated in floodplain clearcuts by planting seedlings without site preparation (Youngblood and Zasada 1991), and this has been reinforced by other operational experiences (Maisch 1993). Machine planting has the advantage of high productivity but is limited to areas of light slash and few stumps (Lowman 1999). Machine planting has been recommended for some areas on the Kenai Peninsula (Peterson and Charton 1999), although hand planting will yield a more natural stand (Landis 1989). Hand planting tools that can be used include the hoedad, planting bar, dibble, shovel, mattock, and powered auger, and planting machines that can be used include furrow, intermittent, and spot planters (Lowman 1999). Some planting failures have been blamed on late season planting (Alden 1985), while late season planting has been shown to be effective in other cases (Maisch 1993).

Direct seeding has been shown to be effective when done with scarification, either as broadcast seeding (Gardner 1983) or spot seeding with or without seeding shelters (Putman and Zasada 1986); however, a potential limiting factor is the increased rate of seed use when seed availability is limited. Densmore et al. (1999) examined direct seeding and planting on burned sites with a variety of site-preparation techniques, and found success with seeding on scarified sites and planting.

Although birch can reproduce either by seed or from vegetative sprouting following harvesting or disturbance, seed regeneration generally predominates (Bell 2000). Little planting of birch has occurred to reforest harvested sites in Alaska and reliance on natural regeneration has been common. Birch seeds annually but seed viability is variable. Natural regeneration is usually adequate for birch (Maisch et al. 2001), but preparation of suitable seedbeds by broadcast burning, mechanical site preparation or logging disturbance is recommended (Perala and Alm 1990), especially in older stands where stump sprouting is limited (Bell 2000). Recent observations indicate that birch regeneration is not always adequate, especially in older stands with a heavy Calamagrostis component (Hanson, 2014 pers. comm.). Even-aged systems are most commonly used to harvest and regenerate birch (Perala and Alm 1990). Browsing by moose can be a problem when trying to regenerate birch (Cole et al. 1999).

There has been recent interest and research in balsam poplar reforestation, mostly in the context of energy production, and mostly with vegetative reproduction, either from cuttings or from coppice regeneration after harvest (Barber 2014, Byrd 2013). The use of hybrids shows promise, but phenology problems with photoperiod have been encountered. Both balsam poplar and aspen readily reproduce from root suckers. Zasada et al (1981) found that increased root sprouting was produced with increased ground disturbance. A study in Alberta found that aspen and poplar regeneration from root suckers could be affected and predicted by varying the retention of mature trees (Gradowski et al. 2010).

A number of documents report the results of reforestation surveys in Region II on State land (Alaska DOF 1995, 2007) and Native Corporation lands (Sanders 2003), and in Region III on

State lands (Sprankle and Putman 2002) and Native Corporation lands (Alaska DOF 2002, Putman 1986). In addition to these documents a reforestation database maintained by the Division of Forestry (D. Hanson, pers. comm.) and recent reforestation surveys conducted by University of Alaska students (M. Morimoto, pers. comm.) and (A. Allaby, pers. comm.) have also examined reforestation results. In most cases, adequate reforestation was observed, however, the Division of Forestry's database indicates some deficiencies in birch regeneration due mostly to *Calamagrostis* competition. An early study by Fox (1980) of post-harvest natural regeneration near Fairbanks yielded variable results. Natural regeneration after the spruce bark beetle infestation on the Kenai met minimum FRPA requirements on some, but not all, areas (Jandreau and Arians 2006). Some of the surveys by Alaska DOF and TCC indicate that seedling recruitment continues for some time post harvest, a point that is reinforced by other current research (Miho reference).

There appear to be few references that address desired stocking levels or optimum tree spacing specifications outside of a Levels-of-Growing-Stock (LOGS) study and derivative studies conducted by the University of Alaska (Hollingsworth 2002, Packee 1999a, Packee 2001). Lower height growth of spruce has been observed at narrowest and widest espacements, and it is suggested that dense spruce stocking may help biologically control *Calamagrostis*. A literature review suggests that when managing for high volume of quality fiber, appropriate espacement levels could be white spruce at 680 stems/acre, paper birch at 435 stems/acre, balsam polar at 300 stems/acre, and quaking aspen at 540 stems/acre (Packee 1999b).

REFERENCES

◆ **Alaska Division of Forestry. 2007.** Timber sale history, Division of Forestry, Coastal Region/MSAO. Unpubl. Report. 13 pp.

Compiler abstract. Packet of information includes data on timber sales in the Mat-Su Area. Tables include data from regeneration surveys in harvest areas.

◆ **Alaska Division of Forestry. 2002.** FPA Regeneration survey, June 2002,Tetlin Reservation lands. Unpubl. report. 4 pp+cover.

Compiler abstract. In June of 2002, the Tok Area forestry staff of the Alaska Division of Forestry conducted a regeneration survey on 21 harvest units on Tetlin Reservation Lands. Harvesting occurred in 1992. Sample plots were taken in one unit; field observation was used to assess compliance in the remaining units. All 21 units surveyed met the guidelines of the FRPA regulations.

◆ **Alaska Division of Forestry. 1995.** Mat-Su regeneration surveys. Unpubl. Report. 12 pp. + notebook.

Compiler abstract. Short reports summarize data from 1995 regeneration surveys on timber sales in the Mat-Su Area.

◆ **Alaska Division of Forestry. 1992.** Tree improvement, nursery and research for interior and southcentral Alaska : a report . I vol. (various pagings)

Author introduction. This report presents the history and current status of renewable forest resource management activity and proposes research opportunities, operational tree-improvement, and nursery programs for interior and southcentral Alaska. It also includes specific proposals for a multipurpose facility at the University of Alaska Fairbanks and a "Teens for Trees" program for local rural youth. This report is not a plan nor does it address responsibilities, funding sources, or program implementation.

◆ **Alaska Division of Forestry. 1989-95.** Regeneration reports from the Valdez-Copper River area. Unpubl. reports.

Compiler summary. Four regeneration surveys were conducted in the Copper River area in the late 1980s-1990s.

- Tazlina Bend: 8.2 acres surveyed in 1989. Results showed a median of 490 trees per acre with an average age of 5.2 years and average height of 2.77 feet.
- Mile 166 Woodlot: 80 acres surveyed within a larger harvest area in 1995. The stand is non-commercial black spruce from which larger white spruce was removed for firewood. Survey results show 1400 trees per acre, including residuals.
- Moose Creek Timber Sale: 67 acres in four units were surveyed in 1995. Unit 1 has adequate regeneration and residual timber; Units 2 and 3 are wet sites with cottonwood and aspen on much of the area along with residual poletimber. These sites are too wet for planting. White spruce will likely come back through natural regeneration. Unit 4 has 800 seedlings/acre on the portions of the unit that were clearcut; the remainder of the unit was selectively harvested and there is a well-stocked stand of residual poletimber.
- Mile 92: 11 acres clearcut surveyed, date unknown. Survey results showed 650 trees/acre with an average age of 2.8 years.

Compiler's note: Field surveys of approximately 15,000 acres of Ahtna land were conducted by DOF staff in June 2002. Field work was completed and analysis undertaken, but a final report was not completed. Oral reports from surveyors said that they were "amazingly surprised" that the results were so good and there didn't appear to be a regeneration problem.

◆ **Alden, J.N. 1991.** Provisional tree seed zones and transfer guidelines for Alaska . United States Department of Agriculture, Forest Service, Pacific Northwest Research Station. GTR-270. 35 pp.

Author abstract. Four hundred and eighty-six provisional tree seed zones were delineated within 24 physiographic and climatic regions of Alaska and western Yukon Territory Estimated forest and potential forest land within altitudinal limits of tree species in Alaska was 51,853,000 hectares (128,130,000 acres) Seed transfer guidelines and standard labeling of seed collections are recommended to reduce losses from maladaptation and maintain the genetic identity and productivity of future forests in Alaska.

◆ **Alden, J. 1985a.** Biology and management of white spruce seed crops for reforestation in subarctic taiga forests. Univ. of Alaska Fairbanks, Sch. of Agriculture and Land Resource Mgmt., Agric. and For. Exp. Sta. Bulletin 69. 51 pp.

Author abstract. Seed production is the most dramatic event in the life cycle of trees and is the first step in forest regeneration. Embryos of white spruce are fragile during germination, and they depend on vigorous seeds for survival and growth. Mortality of white spruce seeds and seedlings is high in northern forests because climate and microhabitat are often unfavorable for seed germination and seedling establishment. Large quantities of high-quality seed are required for natural and artificial regeneration of white spruce forests at high latitudes. The first chapter of this bulletin describes the reproductive process of white spruce and factors that affect cone and seed production and seed quality. Knowledge of the reproduction cycle and factors that affect seed production and quality of white spruce is essential for forecasting and managing seed crops. Evidence that white spruce is a genetically variable species in northern forests is summarized in the second chapter. This chapter includes recommendations for maintaining the gene pool of natural populations and for seed transfer in afforesting sites that do not have endemic populations. A procedure for delineating planting zones for adapted seed sources is described as an alternative for provisional seed zones that only reduce the risk of maladaptation from long-range seed transfer. The final chapter outlines steps in harvesting white spruce seed crops and can be used as a working manual. Practical procedures are described for evaluating quality and quantity of white spruce seed crops, certifying the geographic origin of seed parents, collecting cones, and processing seeds to maintain viability for many years. The genetic structure of white spruce and the environment-embryology relationships that effect seed production and maturation have not been studied in detail. The need for research in the areas of genetics, biochemistry, physiology, and ecology is discussed in each chapter. The results of such research will help to improve seed yields and make the management of white spruce crops more profitable in Alaska and Yukon.

◆ **Alden, J.N. 1985b.** Early survival and growth of white spruce on natural sites. pp. 40-43 in: 37 in: Early results of the Rosie Creek Fire Research Project 1984. G.P. Juday and C.T. Dyrness, eds. Univ. of Alaska Fairbanks Agric. and For. Res. Exp. Sta. Misc. Publ. 85-2. 46 pp.

Compiler excerpt. Survival after the first growing season was unsatisfactory on all sites planted in this study. Mortality was apparently caused by late season planting and unhardened planting stock. Early results of the study show that:
1.. white spruce populations and families in the Bonanza Creek Experimental forest and Rosie Creek Fire areas are inherently different in survival and growth potential. The adverse effects of an unfavorable nursery environment on growth and hardiness of planting stock was greater for the midslope population than for the floodplain and upper slope populations. Only seedlings from native habitats should be grown for artificial reforestation programs to reduce short- and long-term risks of maladaptation. This recommendation applies especially to mild midslope sites.
2. Mortality was higher, and latent winter and early frost injury were more severe at the floodplain site than at the upper slope and midslope sites. Artificial reforestation of the floodplain habitat may require hardier planting stock than artificial reforestation of the upland sites.
3. Unhardened planting stock overwintered more satisfactorily in an unheated greenhouse than outplanted at the floodplain and upper slope sites. unhardened planting stock should not be outplanted in late summer and early autumn in the Bonanza Creek and Rosie Creek Fire areas,

◆ **Barber, V. 2014.** Stooling beds: Poplars as a sustainable biomass energy resource. Agroborealis 44: 37-38.

Compiler excerpt. The Alaska Energy Authority Emerging Energy Technology Fund program provided funding for the stooling beds project being conducted by the State of Alaska's Division of Forestry (in the Department of Natural Resources) and the UAF Forest Products Program, with a goal to adapt, demonstrate, and disseminate inexpensive reforestation methods applicable following woody biomass harvest.

The project's staff harvested more than 4,000 stem cuttings from balsam poplar (*Populus balsamifera*) growing in Palmer and Delta Junction in March of 2013 and stored in a freezer. We soaked the unrooted stem cuttings for a week in late May/early June and planted them in mid-June 2013. We planted logged sites in Matanuska-Susitna Valley (five) and Delta Junction (five) with cuttings. We planted stooling beds that will serve as parent material for future cuttings at two locations, one each in Delta Junction and Palmer, where UAF has research sites with available land. At the Delta Junction and Palmer sites, we planted stooling beds of hybrid poplar, using cultivars of Green Giant, Okanese, and Hill obtained from Canada. We evaluated all planted stems for growth and survival at the end of the growing season.

While the hybrids used in Alaska grew better than the local balsam poplar, there is still a problem with phenology (budset and senescence) and with photoperiod. The light regime in Alaska is very different than lower latitudes. The hybrids that were damaged by the early frost did not harden off as early as the Alaska balsam poplar and thus still retained their leaves when the temperature dropped, while the Alaska trees had already lost theirs. To alleviate this problem, we plan to develop an Alaska balsam poplar hybrid that will better adapt to the changing climate.

◆ **Bell, W. 2000.** White birch regeneration. Pp. 7-8 in Proc. for the Ecology and management of white birch workshop. Sept. 21-22, 1999. Ontario Ministry of Natural Resources, Northeast Science & Technology, Ontario Government Complex, PO Bag 3020, S. Porcupine, ON. 67 pp.

Author summary.
NATURAL REPRODUCTION
• Monoecious species
• Seed regeneration generally predominates over vegetative reproduction following disturbance
• Begins to bear seed at approximately 15 years of age;
• Optimum seed-bearing age is from 40 to 70 years
• Stands age 100 years can produce large quantities of seed
• Relatively large quantities of seed are produced annually, with excellent crops occurring every two to four years and a bumper crop occurring one year in ten
• In Alaska, average quantity of filled seed in four undisturbed stands, for the period of 1958 to 1963, varied from 435,000 - 282,000,000 seeds/ha
• In a study in Maine, seedfall varied from 1,976,800 - 41,512,800 seeds/ha between 1958 and 1960
• Seed averages 3,042,000 seeds/kg (range 1,344,800 - 9,083,000)
• Light, winged seeds are dispersed by wind and water

• Although seeds may be carried considerable distances by wind, but approximately 85 percent falls within two times the tree's height
• Seeds are often blown for greater distances over crusted snow

SEED VIABILITY AND GERMINATION

• Seed quality is highly variable
• Seed viability ranges from 15 to 20 percent
• Germination is related to seed weight and abundance of seed, with heavier seeds having a higher germinative capacity (e.g. germinative capacity of samples of 2.3 and 3.9 mg/20 cc seeds were 46 percent and 72 percent respectively)
• Seeds produced in a bumper seed year germinated faster and better than seed produced in poor seed years
• Seed quality in four undisturbed stands, between 1958 to 1963, averaged 17 percent; filled seed ranged from 434,900 - 281,694,000 seeds/ha; seeds rapidly lose viability
• Some seeds may be stored in the forest floor for at least one year
• Seeds remain viable for up to two years if moisture content is low, but degenerate rapidly in moist conditions
• Because of the small size of white birch seed, newly germinated seedlings are fragile, sensitive to moisture, light, and seedbed conditions germination success and early survival is greatest on mineral soil and rotten logs and lowest on leaf litter
• The majority of seedlings in new stands become established during the first growing season following disturbance, but a small proportion may be added during the second and third years
• Depending on seedbed and climatic conditions, between 20 and 400 birch seeds are required to produce a single one-year-old seedling
• Seedling survival is often higher, at least initially, in shaded positions
• Seedlings require shade for two to three months in the first summer

VEGETATIVE REPRODUCTION

• Prolific sprouting from buds located beneath the bark at the base of the tree, especially when young; sprouting vigor decreases with age
• Begins to lose ability to sprout at approximately age 60

PROPAGATION

• Regeneration by seed is the most important means of reproduction
• The literature presents conflicting reports on birch seed germination
• No pre-treatment, cold stratification, light or fall planting will all result in good germination
• Can be reproduced through layering, cuttings, budding and grafting

SEEDING

• Collect seed while the strobiles are still green, firm, and dry; remove seed by shaking or flailing; separate seeds from debris by screening (0.32 cm screen)
• Seed viability is variable but ranges from 15 to 20 percent
• Store at room temperature for up to two years with moisture content of one to five percent or longer at - 25oC at one to three percent moisture content
• Seed coats contain a germination inhibitor that can be neutralized by stratification or by light. Germination is greatest at 29 to 30oC under bluegreen wavelengths, however, red-light pre-treatment allows white birch to germinate in the dark
• Sow directly under light in the fall or spring plant after stratifying at four to five degrees Celsius for one to three months
• Most nurseries sow in the fall with germination occurring in spring

• Best germination if seeds are held below freezing temperature for six weeks before planting
• Northern sources of seed germinated more rapidly, achieved higher germination, over a lower but wider temperature range, and were more sensitive to pre-chilling (at three degrees Celsius) to promote dark germination than southern seed sources
• Broadcast seed, and cover lightly with soil providing shade for two to three months in the first Summer
• Container seedlings are easier to produce than bare root stock
VEGETATIVE PROPAGATION
• The bark at the base of the tree
• Difficult to propagate by cuttings, but leafy 15 to 20 cm long semi-hardwood cuttings collected in late August and early September treated with 2000 ppm IBA-quick dip or 8000 ppm IBA-talc root well in peat:sand mixtures under mist
• Cuttings treated with a growth-promoting substance may root if planted on mineral soil
• Accelerate cutting growth by placing under long days (16 h), warm day and night (25oC/20oC night) conditions with good air movement and adequate moisture and nutrition
• Do not disturb rooted cuttings until after one natural dormancy cycle
• For best success, shoots should be active, with the base of cutting just becoming firm with no visible terminal bud
• Budding and grafting are practical methods of establishing white birch (Hardy 1989)
MICROPROPAGATION
• Commercially micropropagated
• Shoot tip culture of axillary bud explants from young stem segments leads to shoot proliferation with shoots rooting later
TRANSPLANTING
• Transplants are readily balled and burlapped
• Survival is greater on well-drained, acid, moist, sandy or silty loam soils in full sunlight

◆ **Byrd, A.G. 2013.** Evaluating short rotation poplar biomass on an experimental land-fill cap near Anchorage, Alaska. Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 55 pp.

Author abstract. Biomass energy has enjoyed a resurgence of scientific interest recently. Indeed, biomass may have the potential to replace diesel fuel as the primary source of heating in some parts of Alaska. In addition to forest biomass, short rotation crops have been considered as a sustainable source of woody biomass, and a potential sink for carbon sequestration. In this study, *Populus balsamifera* was evaluated as a short rotation crop for use as an energy source in Southcentral Alaska. Growth and yield rates were measured on an established *P. balsamifera* stand under a two-year rotation, yielding an annual biomass production of 5,530 kg/ha/yr. A fertilizer application study was conducted and demonstrated no effect on growth. Energy content of *P. balsamifera* measured 19,684 kJ/Kg, with a total energy yield of 217,715 MJ/ha after two years. Carbon sequestered below ground was estimated at least 5,338 kg/ha. Biomass may not be carbon neutral, but the carbon emitted from burning biomass is at least partially renewable. With use in high-efficiency boilers, there is potential for biomass to offset costs, and even save money by displacing diesel heating fuel.

◆ **Calogeropoulos, C., D. F. Greene, C. Messier, and S. Brais. 2004**. The effects of harvest intensity and seedbed type on germination and cumulative survivorship of white spruce and balsam fir in northwestern Quebec. Canadian Journal of Forest Research 34:1467-1476.

Author abstract. The effects of different harvest intensities, including uncut, 1/3 and 2/3 partial cuts, clearcuts with and without slash, were investigated on the germination and cumulative survivorship of white spruce and balsam fir over 2 consecutive years. We also investigated the regenerative capacity of both species on three different seedbeds across all harvest intensities. The seedbeds included were mineral, humus, and organic soil. At the germination stage, both species were strongly affected by seedbed type ($p < 0.032$). The germination rates of fir seeds in partial cuts were significantly greater than clearcut treatments, but spruce remained unaffected at this stage by harvest intensity. The addition of slash improved the germination rates of fir relative to the clear-cut plots without slash. The germination rates the following year were reduced on mineral soil for spruce. The cumulative survivorship at the end of the third summer still showed a significant seedbed response for both species ($p < 0.007$) and a significant harvest response for fir ($p < 0.005$). The cumulative survivorship of the second fir cohort was no longer affected by either harvest or seedbed type. Spruce, however, was still affected by seedbed type ($p = 0.006$). The data from this study provide us with a more detailed description of the fate of cohorts recruited following a harvest operation. Still, what remains to be studied is the fate of these cohorts over the next 5–10 years.

◆ **Cole, E., A. Youngblood, and M. Newton. 2003.** Effects of competing vegetation on juvenile white spruce (Picea glauca (Moench) Voss) growth in Alaska. Annals of Forest Science 60:573-583.

Author abstract. We examined the impacts of competing vegetation on survival and juvenile growth of white spruce (Picea glauca (Moench) Voss) on 3 units in south central Alaska and on 3 units in interior Alaska. Treatments consisted of herbicide site preparation and release treatments, and also included a treatment in which competition was minimized for 5 years (weed-free treatment). At all units, the weed-free treatment resulted in significant increases in white spruce height and basal diameter by ages 10 or 11 compared to untreated plots. Average heights and diameters in the weed-free treatments were 1.5 to 3.8 times and 2.0 to 3.8 times those in the untreated plots, respectively. Results from the other treatments differed by unit based on the efficacy of a particular treatment on the vegetation at that unit. For all units, regression equations indicated a significant decrease in diameter at year 10 or 11 with increasing competitive cover and overtopping.

◆ **Cole, E.C., Newton, M., Youngblood, A., 1999.** Regenerating white spruce, paper birch, and willow in south-central Alaska. Natl. Research Council Canada, pp. 993-1001.

Author abstract. The current spruce bark beetle (Dendroctonus rufipennis Kirby) epidemic in interior Alaska is leaving large expanses of dead spruce with little spruce regeneration. Many of these areas are habitat for moose (Alces alces). To establish spruce regeneration and improve browse production for moose, paper birch (Betula papyrifera Marsh), willow (Salix spp.), and three stocktypes (plug+1 bareroot, and 1+0 plugs from two nurseries) of white spruce (Picea glauca (Moench) Voss) were planted in freshly cutover areas on Fort Richardson, near

Anchorage. Four vegetation management treatments were compared: broadcast site preparation with herbicides, banded site preparation with herbicides, mechanical scarification, and untreated control. Spruce seedlings had the greatest growth in the broadcast site preparation treatment ($p < 0.01$). Stocktype was the most important factor in spruce growth, with bareroot transplant seedlings being the tallest and largest 5 years after planting ($p < 0.001$). In the first 3 years, relative stem volume growth was greater for plug seedlings than for bareroot seedlings ($p < 0.001$). By year 4, relative growth rates were similar among all stocktypes. Treatment effects for paper birch and willow were confounded by moose browsing. Results indicate spruce can be regenerated and moose browse enhanced simultaneously in forests in interior Alaska.

Notes (Paragi): Gains from vegetation control seem to increase potential for frost damage based on unpublished data from a separate study they conducted near Fairbanks. "At some point, damage to [spruce] seedlings from frost may outweigh any gains by vegetation control" (p. 999).

For birch, "heavy browsing pressure was sufficient to obscure any differences resulting from site preparation treatments. In areas with light to moderate browsing, size and growth were greater in Site Prep plots than in Untreated plots. On frost-prone sites, repeated top dieback and resprouting minimized treatment effects… Paper birch with repeated top dieback were not browsed as frequently as those without top dieback, presumably because the sprouts were small and inconspicuous... The extent of browsing and top dieback impacts the ability of paper birch to maintain dominance in the stand… Regression analyses indicated that paper birch responded to competition removal. High levels of overtopping and surrounding cover decreased stem volume of both browsed and unbrowsed paper birch seedlings. Thus reducing the competition around seedlings is the most direct means of increasing paper birch growth. The gains will be greater with decreasing browsing pressure and threat of freezing" (p. 999).

Factors in willow planting success and tradeoffs in managing for browse duration and subsequent forest products (conifer and deciduous) are also discussed.

◆ **Densmore, R. V., G.P. Juday, and J.G. Zasada. 1999.** Regeneration alternatives for upland white spruce after burning and logging in interior Alaska. Can. J. For. Res. 29(4): 413-423, 10.

Author abstract: Site-preparation and regeneration methods for white spruce (*Picea glauca* (Moench) Voss) were tested near Fairbanks, Alaska, on two upland sites which had been burned in a wildfire and salvage logged. After 5 and 10 years, white spruce regeneration did not differ among the four scarification methods but tended to be lower without scarification. Survival of container-grown planted seedlings stabilized after 3 years at 93% with scarification and at 76% without scarification. Broadcast seeding was also successful, with one or more seedlings on 80% of the scarified 6-m^2 subplots and on 60% of the unscarified subplots after 12 years. Natural regeneration after 12 years exceeded expectations, with seedlings on 50% of the 6-m^2 subplots 150 m from a seed source and on 28% of the subplots 230 m from a seed source. After 5 years, 37% of the scarified unsheltered seed spots and 52% of the scarified seed spots with cone shelters had one or more seedlings, but only 16% of the unscarified seed spots had seedlings, with and without funnel shelters. Growth rates for all seedlings were higher than on similar unburned sites. The results show positive effects of burning in interior Alaska, and suggest planting seedlings, broadcast seeding, and natural seedfall, alone or in combination, as viable options for similar sites.

◆ **Densmore, R. V. and J.C. Zasada. 1978.** Rooting potential of Alaskan willow cuttings. Canadian Journal of Forest Research, 1978, 8(4): 477-479, 10.1139/x78-070

Author abstract. Rooting potential of cuttings of two riparian and three nonriparian taiga willows was tested under laboratory conditions, and survival of a riparian and a nonriparian species was observed under field conditions. The riparian species, *Salix alaxensis* (Anderss.) Cov. and *Salix novae-angliae* Anderss., rapidly produced roots on all submerged portions of the cuttings. Only a few cuttings of the nonriparian species, *Salixscouleriana* Barratt and *Salix glauca* L., produced roots, and only at the basal end of the cuttings. *Salix bebbiana* Sarg. cuttings did not produce roots.

◆ **Fox, J.D. 1980.** Forest regeneration of upland areas following logging in Interior Alaska. Agroborealis. 12/1979; 12:1

Publisher abstract: A reconnaissance study of post-harvest natural regeneration of upland areas near the Parks Highway made to determine stocking densities of desirable species. Data are tabulated showing frequency and density of tree and non-tree species. While revegetation has occurred, the regeneration of commercial tree species is variable (mainly white spruce, birch, and aspen (Populus tremuloides)). Implications for ecology and management are discussed.

◆ **Gardner, A. C. 1983.** White spruce regeneration options on river floodplains in the Yukon Territory. Environment Canada, Canadian Forestry Service, Pacific Forest Research Centre, Victoria, B.C.

Author abstract. White spruce regeneration options tested on river floodplains of the Yukon Territory, including natural seeding, spot and broadcast seeding and planting on scarified and unscarified ground, were replicated for two years on two sites. Five years after establishment the results indicate that scarification increases seedling survival and growth, that broadcast seeding outperformed spot and natural seeding and that spring planting of container stock is a reliable regeneration technique. The infeasibility of plantation reforestation in the Yukon at present suggests a need for development and refinement of seeding techniques.

◆ **Gingras, J.-F. 1990.** Harvesting methods favouring the protection of advance regeneration: Quebec experience. Forest Engineering Research Inst. of Canada. Tech. Note. TN-144. 8 pp.

Author abstract. This report examines the use of several harvesting systems which can favour the protection of advance regeneration already established on the site before harvesting takes place. The methods studied were modified systems using a feller-buncher with a cable of a clambunk skidder, feller-forwarders, single-grip harvesters with a forwarder, and a prototype feller-delimber. The advantages, disadvantages, and relative efficiency in protecting the regeneration using the different methods are discussed.

◆ **Gradowski, T., Lieffers, V.J., Landhäusser, S.M., Sidders, D., Volney, J., Spence, J.R., 2010.** Regeneration of Populus nine years after variable retention harvest in boreal mixedwood forests. For. Ecol. Manage. 259, 383-389.

Author abstract. Aspen and balsam poplar regeneration from root suckers were assessed in boreal mixedwood forests nine years after logging in a variable retention experiment (EMEND Project—Ecosystem Management Emulating Natural Disturbance) located north of Peace River, Alberta, Canada. Five levels of retention of mature trees (2%, 10%, 20%, 50% or 75% of the original basal area) were applied in stands dominated by aspen, white spruce or mixtures of the two species. Basal area of aspen (or that of aspen plus balsam poplar combined) prior to logging strongly influenced sucker density of aspen (or aspen + balsam poplar combined) and in some cases their growth. Nine years after harvest there was a decline in sucker density and volume ha-1 with increasing retention levels of aspen (or both poplars combined); sucker density declined by 50% when only 20% of the original basal area was left in the stand. Retaining mature spruce trees in the stand had little influence on the number of suckers but did affect their total volume ha-1. Thus, we suggest that by knowing stand aspen and balsam poplar density prior to logging and varying levels of retention of aspen and balsam poplar or conifers at harvest, the density of Populus regeneration can be predicted by managers, thereby allowing them to create a range of mixedwood conditions.

◆ **Graham, J.S., and T.L. Wurtz. 2003.** Survival and Growth of Selected White Spruce Container Stock Types in Interior Alaska. Tree Planters' Notes 50(1): 44-49; 2003.

Author abstract. Survival and growth of white spruce (Picea glauca (Moench) Voss) seedlings raised as 4 different-sized container stock types were followed on 5 harvested sites in the Cache Creek drainage of interior Alaska. Stock types evaluated were 1-0 Ray Leach Pine Cells® (65 cm^3, 4 in^3) and 1-0 Styroblock® sizes 313B (65 cm3, 4 in3), 415B (98 cm3, 6 in3), and 415D (164 cm^3, 10 in^3). After 5 years, survival and height growth were mixed. Ray Leach Pine Cells had a significantly higher rate of survival than seedlings grown in Styroblock 313B containers, but there were no differences among the survival of Ray Leach and the other 2 Styroblock sizes, nor among the Styroblock sizes themselves. Survival of all 4 stock types varied dramatically among sites. Although this experiment was not designed to evaluate site factors, lowest survival rates (25% to 40%) may have been related to the bluejoint grass (Calamagrostis canadensis (Michx.) Beauv.) and fireweed (Epilobium angustifolium L.) cover found in 2 of the sites, and highest survival (90%) may have been related to the slight topographic elevation of 1 site. Seedlings grown in Styroblock containers were substantially taller at planting than those grown in Ray Leach containers; this difference was maintained after 5 y. Stem diameter did not differ significantly among stock types, either at planting or after 5 y. Our results reiterate that seedling out planting performance is a complex f unction of many factors, including stock type, competing vegetation, and microsite, and suggest that more research on the performance of different stock types in Alaska is needed before standard stock types can be identified for various site conditions. Tree Planters' Notes 50(1): 44-49; 2003.

◆ **Greene, D.F. and E.A. Johnson. 1998.** Seed mass and early survivorship of tree species in upland clearings and shelterwoods. CJFR 28(9): 1307-1316, 10.1139/x98-106

Author abstract. We examined recommended sowing densities of 25 North American tree species (26 observations) to measure the relationship between juvenile survivorship and seed mass in large clearings and shelterwoods. Two models for expressing the relationship (simple power law or a cumulative negative exponential adjusted to account for rodent-repellent application and seedbed type) all showed that survivorship is highly dependent on seed mass. For a small seed, mineral soil and thin humus confer roughly equally high survivorship. Leaf litter is very poor, and undisturbed thick moss appears to be the worst possible organic seedbed on upland sites. An examination of 30 records of *Picea glauca* (Moench) Voss survivorship (3- to 6-year-old cohorts) on mineral soil revealed substantial intraspecific variation with only 50% of the values within twofold of the predicted value. [Compiler's note: the paper states, "The source of this considerable variation is not regional. The coefficient of variation for Lees (1970, $n = 9$) at a single site is about the same as for the rest of the data set ($n = 21$). As Lees (1970) study is the only one where seeds are sown annually on rescarified seedbeds, we can infer that the bulk of the variation in Table 5 is ultimately temporal, and a likely causative agent is annual variation in drought intervals.]

◆ **Hollingsworth, J. 2002.** Early height growth patterns of planted white spruce seedlings in Interior Alaska . Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 174 pp.

Author abstract. This study looked at early height growth of planted white spruce Picea glauca (Moench) Voss around the Fairbanks area. The effort focused on two Levels-of-Growing-Stock (LOGS) experimental plantations located in the Bonanza Creek Experimental Forest that incorporated an espacement study. Annual total height was also measured on 16 operational plantations and then compared to LOGS plantations. Average annual total height at Site 2 of the LOGS plantations was significantly greater than at Site 1. A significant difference in height growth between these sites was attributed to differences in aspect. Results showed significant annual total height differences among the espacement plots within the LOGS plantation. The narrowest spacing 1.2 X 1.2 m and widest spacing 3.7 X 3.7 showed a lower annual total height while spacings 1.8 X 1.8 m, 2.4 X 2.4 m, and 3.0 X 3.0 m showed a greater annual total height at age ten. The range of annual total height found at the LOGS sites was not significantly different than the range of annual total height found at the 16 operational plantations. Additionally, path analysis was used to quantify the direct and indirect effects of multiple environmental variables (i.e., percent slope, slope position, competition, aspect, and soil moisture) on growth rate at the operational plantations. It was found that slope position, percent slope, and competition had significant direct effects on growth rate. These results provide insight for resource managers when predicting the height growth of planted white spruce

◆ **Jandreau, R., and A. Arians. 2006**. 2004 Regeneration Survey: Forest Lands on the Kenai Peninsula Exempt from the Reforestation Standards of the Alaska Forest Resources and Practices Act. ADNR Division of Forestry and USDA Forest Service State and Private Forestry, Anchorage, AK. Unpublished. 20 pp.

Author abstract. Some, but not all, forest lands harvested after the spruce bark beetle infestation on the Kenai Peninsula regenerated naturally to the minimum requirements of the Alaska Forest Resources and Practices Act (FRPA). The forest lands that regenerated naturally were those that contained some trees that had survived the beetle outbreak to be left as residuals in the harvested stands.

Regeneration standards under FRPA require that two criteria be met: 1) that the numbers of seedlings and residual trees are adequate, and 2) that those seedlings and residual trees are evenly distributed. For the stands with residual trees, both the numbers and distribution of seedlings and residuals were adequate without requiring additional reforestation work. The areas with few residuals did not meet the standards because the distribution of the residual trees and seedlings was patchy, and for plots harvested in the summer without residuals, the number of seedlings and residuals was inadequate. These results indicate that the number of residuals left after harvest plays an important role in whether the reforestation standards can be met naturally.

The numbers of seedlings found in stands with residuals were significantly higher than in stands with few residuals, probably because of the additional seed source provided by the mature trees, and also possibly because of the shade provided by the trees, which appears to limit the abundance of grass (mostly *Calamagrostis canadensis*). The grass appears to be a competitor with seedlings for resources, since seedlings were less abundant in plots dominated by grass than by other types of vegetation. Stands with few residual trees present had higher occurrences of grass as the dominant vegetation. The season of harvest, our surrogate for amount of soil disturbance during harvest, did not appear to directly influence seedling abundance. However, grass-dominated plots were less abundant in plots that were harvested in the summer (and thus had probably experienced more scarification as a by-product of harvest). Season of harvest, then, may indirectly affect seedling regeneration because of its effect on grass abundance.

◆ **Landis, T.D. 1999.** Seedling stock types for outplanting in Alaska. pp. 78-84 in: Proc. of the Alaska Reforestation Council April 29, 1999 Workshop. Anchorage, AK. Univ. of Alaska Fairbanks Agric. & For. Exp. Sta. Misc. Publ. 99-8. 85 pp.

Author abstract. Project objectives, outplanting site conditions, the outplanting window, and type of planting tool should be considered when defining the target seedling for Alaskan reforestation projects. Although machine planting may be most economical, hand planting with seedlings of different species and sizes will result in a more natural stand. Based on the objectives of the Kenai Restoration Project, I recommend planting large-volume container spruce seedlings that have been chemically root pruned. Due to economic constraints however, this ideal may have to be reduced to smaller stock. If this is the case, some larger target seedlings should still be plated to compare survival and growth, the true tests of outplanting performance.

◆ **Landis, T.D., R.K. Dumroese, and D.L. Haase. 2010.** Seedling Processing, Storage, and Outplanting, The Container Tree Nursery Manual . USDA Agriculture Handbook 674, Vol. 7.

Introduction. The Container Tree Nursery Manual has been functionally organized to follow the normal sequence of nursery development, seedling propagation, and outplanting. Volume one discusses the various steps that should be followed in developing a nursery facility. Volume two is concerned with the selection of types of containers and growing media. Volume three and volume four analyze the “limiting factors” that affect seedling growth and discuss how they can be manipulated in container nurseries. Volume five examines the various biological organisms that can affect seedlings, either negatively as pests or positively as mycorrhizae. Volume six shows how to develop growing schedules and how seedlings are propagated through the three growth phases. Volume seven covers the time from when the crop is hardened-off and ready for harvest to when they go in the ground.

◆ **Lowman, B. 1999.** Tree planting equipment. pp. 74-77 in: Proc. of the Alaska Reforestation Council April 29, 1999 Workshop. Anchorage, AK. Univ. of Alaska Fairbanks Agric. & For. Exp. Sta. Misc. Publ. 99-8. 85 pp.

Author abstract. Planting equipment must be compatible with stock type and site conditions for quality reforestation programs. Among the hand tools used for planting are the hoedad, planting bar, dibble, shovel, mattock, and powered auger. Planting machines include furrow, intermittent, and spot planters. Machine planting reduces labor costs and has relatively high productivity. Machines plant as many trees in an hour as a person using a handtool plants in a day, about 600 seedlings. Machines are used in moderate terrain, good soil, few stumps or obstacles, and light slash. Inspections have shown very little difference between the two methods. Hand planting tools are used to plant the majority of trees.

◆ **Maisch, J.C. 1993.** Reforestation on Alaska Native lands. Alaska branching out. Aug. 1993. 12(3): 1.

Compiler summary. This article summarizes tree planting operations on Toghotthele Corporation lands and a native allotment near Nenana in 1992-93. Approximately 205 acres were scheduled for planting in 1993 with white spruce seedlings grown in containers and purchased from Pelton Reforestation Ltd. of British Columbia, Canada. The one year old seedlings were grown from seed collected from the same lands targeted for reforestation. The planting crew is comprised of shareholders of the Toghotthele Corporation and the forestry program staff of the Tanana Chiefs Conference, Inc. (TCC). In 1992 the crew planted 100,000 seedlings on other units of Toghotthele lands. Approximately 680 seedlings are planted per acre using 8' by 8' spacing. Over a 6 hour period, each planter is able to sow approximately 650 seedlings. A planter earns 15 cents for each seedling planted. TCC monitors planting operations and collected planting cost data which will be included in a report on reforestation costs on private land in Interior Alaska for publication in the Northern Journal of Applied Forestry.

◆ **Maisch, J.C., J. Alden, and S. Clautice. 2001.** FRPA reforestation workshop summary. 2001. Alaska Reforestation Council, Inc. Forest Tree Improvement Cooperative. Fairbanks, AK. Unpubl. report. 3 pp.

Compiler excerpt. Conclusions were that planting is recommended for white spruce regeneration, whereas natural regeneration is usually adequate for hardwood species. Site preparation is recommended for natural regeneration, except where aspen is a significant harvest component. White spruce regeneration will benefit form site preparation, especially when dense competition is anticipated. Site preparation and planting are less expensive and more successful if they are accomplished immediately after forest disturbance. Reforestation practices used in Alberta provide useful comparisons for regeneration procedures in Alaska.

◆ **Martin-DeMoor, J., V. J. Lieffers, and S. E. Macdonald. 2010.** Natural regeneration of white spruce in aspen-dominated boreal mixedwoods following harvesting. Canadian Journal of Forest Research 40:585-594.

Author abstract. In some boreal forests sites, there are considerable amounts of natural regeneration of white spruce (Picea glauca (Moench) Voss) after logging, even without silvicultural treatments to encourage establishment. We assessed the factors controlling the amount of this regeneration 8–15 years postharvest on previously aspen-dominated (Populus tremuloides Michx.) boreal mixedwood sites. We surveyed 162 transects across 81 cutovers, exploring the effects of mast years, season of harvest, distribution of seed trees, weather conditions around the time of harvest, and abundance of grass or woody vegetation on white spruce regeneration. Substantial amounts of naturally regenerated white spruce were found; however, sites with no seed trees had virtually no spruce regeneration. Average stocking was 7% (percentage of 9 m2 plots along a transect across a cutover that had at least one seedling), ranging from 0% to 62%. Stocking levels were higher in cutblocks that had been harvested in the summer, prior to seedfall of a mast year, and where there was a seed source within 60 m. Stocking was lower when conditions were cool and wet the year before and 2 years after harvest and when the site contained extensive cover of grass or woody vegetation.

◆ **Martinsson, O., Packee, E.C., Gasbarro, A., Lawson, T., coords. 1989.** Forest regeneration at northern latitudes close to timber line. Proceedings, 7th annual workshop on silviculture and management of northern forests: 1985 June 16-20; Lulea, Gallivare, and Ostersund, Sweden. Gen. Tech. Rep. PNW-GTR-247. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 73 p

Compiler abstract. These proceedings include a series of papers on reforestation and afforestation in Scandinavia, primarily with Scots pine *(Pinus sylvestris)*. The collection also includes papers on secondary Korean pine-deciduous forests in Korea, and regeneration of Dahurian larch *(Larix gmelini)* in China.

◆ **Murray, M. 1980.** Forest regeneration at high latitudes . Pacific Northwest Range and Experiment Station. Portland, OR. 56 pp.

Summary. The proceedings of a fifth international workshop sponsored by the School of Agriculture and Land Resources, University of Alaska-Fairbanks in cooperation with the Division of Forestry, State of Alaska and the Alaska State Society of American Foresters, August 15, 16, 17, 1983, Fairbanks, Alaska, U.S.A.

◆ **Newton, M. 1996.** Adaptability of tree seedlings for forest regeneration in southcentral Alaska. Alaska branching out. 15(3): 1-2.

Conifer regeneration in Alaska, like everywhere else, is subject to many environmental problems during the decades immediately following establishment. Herbaceous and shrubby vegetation, in particular, represent the largest single cause of regeneration failure. After beetles have begun to attack mature stands, crowns open gradually over a period of several years, perhaps ending with negligible residual overstory. The opening process tends to favor shade-tolerant species already

present in understories, and also invite invader species. Herbaceous species, especially *Calamagrostis canadensis* and *Epilobium angustifolium* are especially abundant after spruce has collapsed. When these herbs are mixed with residual and invasive alders, regeneration has negligible chance of establishment. When added to the tendency for large, seed-bearing spruces to be among the first to die, natural regeneration are scant even where understory cover may be light. On the more productive sites, the beetle-kill stands may be merchantable and be suitable for logging. On these sites, the productive soils are especially prone to herb development. After logging, there is a brief window of opportunity when competition is compatible with establishment of new natural seedling. In the absence of a
decent seed year or source, planting is the only way of capturing this opportunity without major investments in vegetation control. Planting is usually done with containerized spruce seedlings. These may fare reasonably well if planted immediately after logging so that they are becoming established while cover is developing. Large plugs grow better than small ones, so cost control should not be allowed to sacrifice size. However, waiting even a year or two greatly increases the risks to any small plant, and especially those in which we have an investment.
Safe, effective techniques of weeding greatly increase chances of success and growth rates. Use of large transplant seedling, such as plugs that have been transplanted a year or more in a bareroot nursery (p-1 or p-2 for those spending one or two years in transplant beds) are much larger, and have substantial growth advantages. Their relative advantages may be greatest if planted where herb cover has already developed, i.e. their use substitutes for weed control without the cost of weeding. When we combine transplants with either weed control, or planting before weeds develop, we observe that growth is greatly increased and dominance over early successional cover is assured. However, planting is costly, and transplants are more costly than plugs. It is likely that transplants will be less costly per successfully established dominant tree than alternative regeneration strategies if sites have some cover on them. Transplants grown with little competition are also potentially able to make the site appear
to be much more productive than natural stands would indicate, if Oregon experience and preliminary Alaska data are valid. On marginal sites, dense plantations of transplants would cost as much to establish as the stands would yield 100 years hence. Thus, where the objective is to perpetuate the white spruce forest, a low-density planting of the largest available stock is appropriate for sites that have already developed some cover. Low-density plug planting will likely succeed where cover is mostly absent. But cost realities favor the evaluation of aerial seeding on newly logged sites as perhaps the only feasible way of reforesting the large areas involved. At present, no data exist with which to compare stocking distribution and growth after dissemination of treated seed with those of planted stock.

◆ **Ott, R.A. 2005b.** Natural regeneration potential in interior Alaska. PowerPoint presentation. 24 slides.

Compiler excerpt. This presentation summarizes advantages and disadvantages of natural regeneration, with an emphasis on white spruce; regeneration requirements of the Alaska Forest Resources & Practices Act (FRPA); and a summary of Division of Forestry and Tanana Chiefs Conference regeneration surveys.

Advantages include

- Seeding-in over a period of years reduces risk of regeneration being wiped out by unusual weather, pest outbreaks, etc.
- Clumped distribution and dense stocking allows selection of superior crop trees during thinning.
- Seedlings usually become established on appropriate microsites.
- Slower-growing natural regeneration may have better wood quality than rapidly growing plantation stock.
- Clumped distribution may produce better stem form and earlier self-pruning.
- Roots less susceptible to deformation than those of planted seedlings.
- Seedlings better acclimated than newly planted nursery stock.
- Clumped distribution may protect against damage (e.g. wind, snow).
- Maintains genetic diversity in regenerating forest and assures that regeneration is locally adapted.
- If successful, avoids costs and associated administrative, logistical, and environmental constraints of planting.
- Suited to remote areas, areas where local provenances not available, areas where small-scale industry does not warrant nursery program, and areas where alternatives to large clearcuts are needed to maintain non-timber values.

Disadvantages include:

- High degree of uncertainty caused by sporadic seed crops, lack of control over ecological factors controlling germination and establishment, and high rates of seedling mortality.
- Stocking uneven, clumped, may require pre-commercial thinning.
- Most large clearcuts will be insufficiently stocked.
- Natural seedlings have slower initial growth rates than healthy planting stock.
- Tiny seedlings less able to withstand competing vegetation than large, healthy planting stock.
- Leave strips and trees required to act as seed source are subject to blowdown.
- Harvesting of leave strips and seed trees may cause damage to natural regeneration.
- Limits opportunities for tree improvement through selection of superior provenances or genetically improved stock.
- Requires alternatives to large clearcuts (e.g. shelterwoods, patch or strip cuts) which tend to cost more than conventional logging.
- Requires that silviculturists exercise control over harvesting operations to ensure adequate seed supply and seedbed conditions.

The author concludes that required average stocking under the FRPA was usually not achieved within five years after harvest when relying strictly on natural regeneration within the . Seedling distribution was not assessed. Requirement was not achieved the majority of the time when relying strictly on natural regeneration

◆ **Packee, E.C. 2001.** Reforestation stocking standards. Agroborealis 33(2):23- 24.

Compiler excerpt. The objective of this study is to determine for Alaska's Northern Forest species the effect of planting espacement on stem size and characteristics, yield per acre, stand structure, and wood quality. A second objective is to recommend espacement guidelines for both Alaska's Northern Forest and Coastal Forest species. Espacement impacts forest tree characteristics which in turn affect stand structure, wood quality, wood volume per acre, and ecological process (especially succession and soil processes).

Levels-of-Growing Stock (LOGS) plantations with espacements of 4x4, 6x6, 8x8, l0xl0, 12xl2 feet were established at two locations (Bonanza Creek near Fairbanks and at Tok). Survival and height have been measured annually. Once the majority of trees reach one-inch in diameter at breast height or 15 years of age, diameter will be measured and plots will then be measured at three or five year intervals. An ongoing literature review addresses the impact of espacement on tree characteristics. To ensure that aboveground competition is only that of the species being studied, hardwoods and conifers are routinely removed.

Plots at Bonanza Creek and Tok were remeasured and cleaned of competing vegetation. The 10-year results for Bonanza Creek were published. At Bonanza Creek, height growth of white spruce at 15 years of age continues to be least at the narrowest and widest espacements. Diameter growth at Bonanza Creek will be measured in spring 2001 before growth begins-most trees are measurable, with many trees over one inch in diameter. Understory vegetation distinctly differs between the widest and narrowest espacements; at narrowest espacement crown closure has occurred and self-pruning has begun. Observations in spruce indicate that gall aphids *(Adeleges* and/or *Pineus)* severely attack spruce in open-grown conditions; a senior thesis has been proposed to determine the insect and the impact.

Initial espacement guidelines are a discussion point in terms of the Alaska Forest Practice Regulations and Guidelines. At the narrowest espacement, the grass, *Calamagrostis canadensis*, a commonly strong competitor, is weak and being crowded out whereas in the wider espacements it is present, forms a sod, and is a vigorous competitor for summer moisture. This suggests that dense stocking of spruce may biologically control the grass.

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◆ **Packee, E.C. 1999a.** Initial stocking, wood quality, and stand yield. Pp. 6-18 in: Proc. of the Alaska Reforestation Council April 29, 1999 Workshop. Anchorage, AK. Univ. of Alaska Fairbanks Agric. & For. Exp. Sta. Misc. Publ. 99-8. 85 pp.

Author abstract. Regulation of espacement, or initial stand stocking, is the most powerful approach available for managing forest stand yield and wood quality. Stand stocking affects know size and frequency, reaction wood, corewood (juvenile wood), taper, spiral grain, micro-fibril angle, wood specific gravity, and per acre yield. Low stocking results in fast tree growth, but reduces fiber quality and per acre volume, whereas high stocking results in slower tree growth, higher fiber quality, and greater merchantable wood volume per acre. The two basic approaches result in substantially different outcomes and opportunities. Impacts on wood quality and yield are discussed and espacement guidelines for Alaskan species are suggested.

◆ **Packee, E.C. 1999b.** Initial forest stand density and wood quality: a preliminary report. Agroborealis 31 (1): 24-27.

Compiler excerpt. In 1984, the Agricultural and Forestry Experiment Station (AFES) began studying the Growth and Yield of Alaska's Northern Forest. Part of that program is a Levels-of-Growing-Stock (LOGS) study. A LOGS study addresses stand density regulation. The AFES study has two components: espacement, which refers to initial stocking and spacing, which refers to precommercial thinning. Both affect growth rates and tree characteristics. Individual tree characteristics impact wood quality. In 1998, a review of the international literature on the effects of espacement on wood quality, especially Alaska species, was initiated. Emphases are on the impacts of espacement and spacing on per acre fiber yield and wood quality; initial stocking levels to obtain high volume per acre yields of quality fiber are suggested.

Preliminary Espacement Guidelines for Alaska Species (Northern Forest)

Species	**Stems/acre**	**Spacing in feet**
Tamarack	680	8 x 8
White spruce	680	8 x 8
Black spruce	800-680	7 x 7 – 8 x 8
Paper birch	435	10 x 10
Balsam poplar	300	12 x 12
Quaking aspen	540	9 x 9

These guidelines are based on the literature, interpretation of guidelines from other regions, guidelines for similar species, information from various private entities, and personal observations across North America. Several colleagues in the private sector have indicated that their organizations have changed from being proponents of fast growth of individual trees to advocates of high volume per acre and associated higher quality wood fiber. Suggested espacements can be used, also, as stocking targets for survival at the free-to-grow stage of stand development or as early stand spacing targets. Tree geometry, tree height, crown diameter, and crown volume which define growing-space utilization, is largely the basis for the recommendations. To fully utilize the site requires crow occupation of available growing space. The guidelines are for single-species stands. Mixed stands, depending upon the species' shade tolerance. Can have an average, lesser, or greater espacement.

Encouragement of side-shading to cause natural pruning of branches, at least on the butt log (12 to 16 feet), is also desirable. Pruning of the best 200 to 300 crop trees per acre may be an attractive investment alternative to spacing or thinning or may be used in combination with spacing. Pruning desirability is species dependent as well as market dependent.

◆ **Paquette, A., A. Bouchard, and A. Cogliastro. 2006.** Survival and growth of under-planted trees: A meta-analysis across four biomes. Ecological Applications 16:1575-1589.

Author abstract. The transformation of natural forest regeneration processes by human activities has created the need to develop and implement new models of forest management. Alternative silvicultural systems such as variable retention harvest, partial and patch cuts, and older forest management practices such as under-planting, are used in many forests around the world, particularly in North American oak stands, the boreal and coastal temperate rain forests of Canada and the United States, and in many degraded tropical regions of Asia and the Americas. Specific objectives are pursued in each of these biomes, but some are common to most regions, such as preservation of cover and structure and their associated benefits for natural or artificial regeneration due to moderation of the microclimate, development of optimal light and competition conditions, and reduced predation by herbivores. Shelterwoods are often presented

as an alternative to clear-cutting to improve the survival of planted trees. A meta-analysis of published results with randomization tests was performed to test the relationship between overstory density and planted seedling growth and survival. Multiple comparisons were also used to reveal optimal levels of overstory density, if they exist. A majority of studies show that survival and growth improve as stand density decreases to an intermediate level, below which they either drop or stabilize. This level seems optimal in most conditions, as it is also more apt to fulfill other objectives imposed on today's forest activities, such as the conservation of forest processes and structures, and the reconstruction of degraded stands through the accelerated return of mid- to late-successional species.

◆ **Peltzer, D.A., Bast, M.L., Wilson, S.D., Gerry, A.K., 2000.** Plant diversity and tree responses following contrasting disturbances in boreal forest. For. Ecol. Manage. 127, 191-203.

Author abstract. We determined the abundance and diversity of vascular plants in seven types of disturbance in mixed-wood boreal forest. Disturbance treatments included wildfire, natural regeneration after harvest and several methods of silvicultural site preparation. Relative to undisturbed forest, all disturbance treatments increased plant diversity to about the same extent. The abundance of plant growth-forms differed significantly between disturbance treatments. Silvicultural treatments involving soil disturbance (disk-trenching, drum-chopping and blading) had higher cover of grasses and annual forbs; naturally regenerated and cultivated treatments contained more perennial forbs and shrubs. Thus, different post-disturbance plant communities established following contrasting types of disturbance. Plant community biomass and tree growth varied among disturbance treatments. Shoot mass of aspen (Populus tremuloides Michx.) and the root mass of all species declined significantly with increasing soil disturbance intensity. Aspen and white spruce (Picea glauca (Moench) Voss) differed in their response to disturbance. Aspen growth was similar among disturbance treatments. In contrast, aspen density was significantly lower in disk-trenched and bladed treatments than in burned or naturally regenerated treatments, and aspen basal area was significantly lower only in drum-chopped treatments. White spruce grew fastest in drum-chopped sites. Burned treatments had the highest recruitment of volunteer spruce seedlings (up to 3200 ha(-1)), but not significantly higher than in other disturbance treatments. Taken together these results suggest that the most intensive silvicultural treatments had the expected effects of reducing aspen abundance and increasing the growth of spruce, but also contained more grasses and forbs and had lower total root mass than burned or naturally regenerating sites. Further work is needed to examine long-term productivity and the persistence of both native and persistent weedy species following contrasting types of disturbance.

◆ **Perala, D.A., and Alm, A.A. 1990.** Regeneration Silviculture of Birch: A Review. Forest Ecology and Management, 32: 39-77.

Author abstract. The birches are most commonly regenerated using even-aged systems, primarily clearcutting. Clearcut sizes range from 16 ha down to 0.4-ha patches. Seed trees or shelterwoods are sometimes used to provide additional seed and site protection. Uneven-aged systems are not recommended, with the exception of group selection for yellow birch. Coppice systems do not provide full stocking except in short-rotation biomass culture, but coppice provides acceptable supplemental regeneration.

Natural regeneration by seeding prevails because it is economical and highly reliable where the water balance is favorable. Yellow birch sometimes regenerates in advance, but otherwise the canopy, understory, and seedbed must be manipulated to meet germination and seedling-establishment requirements. Suitable seedbeds are prepared by burning, by mechanical site-preparation equipment, and sometimes by the logging process itself. Draining often is all that is necessary to regenerate peatlands. Seedlings should be protected from grazing or browsing. Relatively few stands are regenerated artificially. Direct seeding (either broadcast- or spot-sowing) is usually reliable. Planting is more common and gives the opportunity to introduce exotic or genetically improved stock. In species trials, silver birch has consistently grown faster - and yellow birch slower - than either hairy birch or paper birch. Phenotypically selected natural stands and controlled pollination produce progeny that grow in volume from 30 to 80% faster than average. Thorough site preparation, fertilization, mulching, weed control, and protection from animals benefit seedling growth. Both bare-root and container-grown stock are planted successfully.

Birch is highly regarded for afforesting mine spoils, drained or worked-out peatlands, abandoned and abused agricultural lands, heaths, previously flooded lands, and areas with high air pollution. Fertilizers are often applied to improve site quality. Birch nurse crops benefit conifers by protecting them from frost, insects, and pathogens; by improving the soil through nutrient cycling; and by increasing stand wind-firmness on shallow soils. The optimum proportion of birch in mixed stands is 17–25%. Overly dense birch should be controlled with chemicals, by hand, or with machinery to allow optimum conifer development.

◆ **Peters, V.S., S.E. Macdonald, M.R.T. Dale. 2006.** Patterns of initial versus delayed regeneration of white spruce in boreal mixedwood succession. Can. J. For. Res. 36(6): 1597-1609.

Author abstract: The timing of white spruce regeneration in aspen (*Populus tremuloides* Michx.) – white spruce (*Picea glauca* (Moench) Voss) boreal mixedwood stands is an important factor in stand development. We examined boreal mixedwood stands representing a 59-year period of time since fire and determined (1) whether and when a delayed regeneration period of white spruce occurred, (2) whether the relative abundance of initial (<20 years) versus delayed (≥20 years postfire) regeneration is related to seed availability at the time of the fire, and (3) what are the important regeneration substrates for initial versus delayed regeneration. Initial regeneration occurred primarily on mineral soil or humus, while delayed regeneration established primarily on logs and peaked 38–44 years after fire. Of the 20 stands investigated, seven were dominated by initial regeneration, six were dominated by delayed regeneration, and seven were even mixtures of both. The dominance of a site by initial or delayed regeneration could not be simply explained by burn timing relative to mast years or distance to seed source; our results suggested that fire severity and the competitive influence of initial regeneration on delayed regeneration were important at fine scales. Based on our results we describe several possible postfire successional pathways for boreal mixedwood forests.

◆ **Peterson, A. and J. Charton. 1999.** Advantages and disadvantages of machine planting in south-central Alaska. pp. 68-73 in: Proc. of the Alaska Reforestation Council April 29, 1999 Workshop. Anchorage, AK. Univ. of Alaska Fairbanks Agric. & For. Exp. Sta. Misc. Publ. 99-8. 85 pp.

Author abstract. Planting machines have been used as reforestation tools for decades, but until 1995, they were not used on a large scale in Alaska. Major disadvantages are: high costs for purchase, transport and operation; limited use on steep slopes; access restrictions; potential for residual tree damage; and increased seedling mortality from wildlife injuries. Despite these disadvantages, machine planting has numerous advantages in Alaska, including mineral seedbed preparation (as part of the planting operation), improved survival, and high planting rates at low cost. For many areas on the Kenai Peninsula, machine 0lanting is the most effective method of restoring forest ecosystems ravaged by spruce beetle epidemics, wildfire, and timber harvests.

◆ **Pétursson, J.G. and A. Sigurgeirsson. 2005**. Direct seeding of boreal conifers on freely drained andosols in Southern Iceland. 28512 Búvísindi 04 20.1.2005 9:15 Page 15

Author abstract. The success of a direct seeding trial in southern Iceland was evaluated throughout four growing seasons. The trial involved comparison of the three coniferous species most commonly used in Icelandic forestry lodgepole pine (Pinus contorta Dougl. var. contorta), Sitka spruce (Picea sitchensis (Bong.) Carr.) and Siberian larch (Larix sibirica Ledeb.) and five seeding methods: (1) control, (2) plastic cone, (3) pyramidal indentations, (4) cover with gravel and (5) cover with pumice. For comparison, one-year old seedlings were planted in the spring and autumn. The seedling emergence for all species and seeding methods was 11.3% after the first summer and 19.0% after the second. Seedling emergence was significantly higher for lodgepole pine (41.3%) than for Sitka spruce (26.8%) and Siberian larch (22.6%). Sowing under a plastic cone gave the highest seedling emergence or an average of 50.3% for all species. Seedling mortality was high after the first winter, except under the cones, where more than 80% of the seedlings survived. After three winters the highest survival was found for lodgepole pine, where 19.7% of the viable seed yielded established seedlings, compared to 10.9% for Siberian larch and 9.2% for Sitka spruce. The number of seeding spots having at least one live seedling after three growing seasons ranged from 50 to 76% for lodgepole pine, 2.5 to 45% for Sitka spruce and 6.6 to 40% for Siberian larch. Survival of planted seedlings differed between planting seasons, with spring planting yielding better survival for Sitka spruce and lodgepole pine and autumn planting for Siberian larch. Lodgepole pine gave the most promising results for establishment by direct seeding. From the fourth year establishment ratios, it can be concluded that the use of plastic cone-shelters is the most promising method of direct seeding and appears to provide establishment success comparable with planting.

◆ **Putman, W.E. 1986.** Togotthele Lands 1984 Regeneration survey. Tanana Chiefs Conference Unpubl. Report.38 pp.

Compiler abstract. In 1984, the Tanana Chiefs Conference, Inc., Bureau of Indian Affairs, and Toghotthele Corporation, completed a forest regeneration survey on Toghotthele Corp. lands. The lands surveyed had been logged under contracts administered by the State of Alaska prior to conveyance of the land to the Toghotthele Corp. Portions of some harvest units were planted with white spruce one to five years prior to the surveys. The report documents regeneration on cutover areas, and makes recommendations for future management. The report assumes that white spruce is the favored crop tree, and that management will aim to establish white spruce in harvested areas. Overall, all units were adequately stocked with acceptable tree species (birch, aspen, balsam poplar, and white spruce). White spruce was present on 53% of the stocked plots.

◆ **Putman, W.E. and Zasada, J.C. 1986.** Direct seeding techniques to regenerate white spruce in interior Alaska. Canadian Journal of Forest Research, 16: 660-664.

Author abstract. Direct seeding techniques for regenerating white spruce (Picea glauca (Moench) Voss) were tested on 12 logged areas near Fairbanks, AK. Techniques examined included spot seeding on scarified seed spots with and without plastic cone shelters and spot seeding on nonscarified seed spots with and without plastic funnel shelters, all at three sowing times. After the second growing season, scarified treatments produced greater seedling survival. Cone shelters usually produced greater survival than unsheltered seeding on scarified seed spots and funnel shelters usually produced greater survival than unsheltered seeding on non-scarified seed spots. Sowing time had little effect on survival.

◆ **Sanders, R.C. 2003.** Summary of reforestation on Tyonek Village lands harvested by Gates Construction 1999 to 2003. Unpublished. 14 pp.

Compiler abstract: This study was done to prepare a status summary of tree regeneration and areas that will benefit from mechanical scarification on recently harvested tracts. Harvests were partial cuts of white spruce during a spruce bark beetle outbreak.

◆ **Sprankle, J. and W. Putman. 2002.** Reforestation survey report of State of Alaska timber sales in the vicinity of Cummings Road. Unpubl. Report by Tanana Chiefs Conf. for State of Alaska, DNR Division of Forestry. 36 pp.

Compiler abstract. In early June 2002, forestry staff at Tanana Chiefs Conference, Inc. (TCC) conducted a reforestation survey of several harvested site on state land in the Delta Area. These surveys were targeted to include the lowest known stocked harvest units in the management area. Intensive surveys were conducted on six units within two sales. In addition, extensive evaluations were done on multiple units in eight sales where successful regeneration was obvious. The intensive surveys assessed stocking levels and quality. The six units surveyed ranged from 70% to fully stocked. The authors reported that all the units in the extensive evaluations were satisfactorily stocked with white spruce and /or hardwood reproduction. Most units were overstocked and several would benefit from pre-commercial thinning. Most units also had a significant amount of residuals saplings, poletimber, and sawtimber that was not harvested during logging operations. Some larger residual trees were damaged from felling and skidding operations. These trees do not necessarily add to the health of the future stand but add benefits for wildlife.

◆ **Tanana Chiefs Conference, Inc. and Alaska Division of Forestry. 1989.** Forest regeneration in the coastal and interior regions of Alaska. Unpubl. report. Feb. 7, 1989. 18 pp.

Author abstract. The following paper has been prepared at the request of the Forest Practices Act Review Committee to provide members of this group with current information on the status for forest regeneration as it is practices by public and private forest managers. The paper discusses forest regeneration in both the coastal and interior regions of the State. Common terminology used by foresters is defined and a brief description of the silvics and management practices for the major tree species off each region is presented. Historical data on regeneration practices on private and public lands and a section discussing the backlog of lands requiring reforestation are examined. An overall summary and recommendations statement concludes the paper.

◆ **Tousignant, D. 1995.** Effect of tree flowering and crown position on rooting success of cuttings from 9-year-old black spruce of seedling origin . Can. J. For. Res. 1995, 25 (7) 1058-1063.

Author abstract. Cuttings were taken at different levels in the crown of both flower-bearing and sexually immature 9-year-old black spruce seedlings (*Picea mariana* (Mill.) B.S.P.). We obtained satisfactory rooting success, despite the relatively old age of the trees. The rooting percentage of the cuttings taken from the lower third of the crown was significantly higher ($p <$ 0.01) than that of the cuttings originating from the middle and top thirds of the crown (53%, 36%, and 29%, respectively). Cuttings from the upper portion of the crown showed persistent signs of advanced maturation, while those from the bottom of the crown regained an almost juvenile appearance after rooting. Surprisingly, the cuttings taken on flower-bearing trees rooted better ($p <$ 0.10) than those taken on sexually immature trees (48% vs. 30%). Large and significant differences were also recorded between individuals of both groups. No significant interaction was found between sexual maturity and crown position of the cuttings for rooting percentage. The effects of maturation on the rate of rooting and the relevance of replacing grafting by rooting for certain purposes are discussed.

◆ **van Hees, Willem W.S. 2005.** Spruce reproduction dynamics on Alaska's Kenai Peninsula, 1987-2000. Research Paper PNW-RP-563. Portland, Oregon: USDA Forest Service, Pacific Northwest Research Station. 18 p.

Author abstract: During the past 30 years, spruce forests of Alaska's Kenai Peninsula have undergone dramatic changes resulting from widespread spruce bark beetle (*Dendroctonus rufipennis* (Kirby)) infestation. In 1987 and again in 2000, the Pacific Northwest Research Station's Forest Inventory and Analysis Program conducted initial and remeasurement inventories to assess broad-scale impacts of this infestation.

Changes in regeneration of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and white spruce (*Picea glauca* (Moench) Voss) are examined by using data collected on 130 plots. Regeneration of Sitka and white spruce in terms of mean number of seedlings per plot is not significantly different from the 1987 findings. The number of plots where seedling stocking remained at previous levels or increased, slightly exceeded the number of locations where seedling stocking declined. Almost half the plots (49 percent) had decreased numbers of seedlings, and almost 72 percent of the plots fell in the less-than-fully-stocked category in both inventories. Also, the distribution of the seedlings over the plot was not uniform. No plots had seedlings on all plot cluster sample points in either inventory.

◆ **Wahrenbrock, W. 2014.** Reforestation techniques. Unpubl. E-mail from Wade Wahrenbrock (Kenai Pen. Borough) to Hans Rinke (AK Div. of Forestry), May 13, 2014. 1 p. + photos.

Compiler note. Wahrenbrock visited a tract of state land near Anchor Point that were salvage logged in about 2000-2002. After logging, the site was dominated by *Calamagrostis* with almost no natural regeneration of trees. In 2012, under the Kenai Peninsula Borough spruce bark beetle mitigation program the site was treated with mastication and about 250 trees per acre were planted. Survival seems very good; probably around 95%. The trees happened to be planted when the rabbit/hare population was hitting a peak. Rabbits munched on many of the planted trees but they killed very few --- just set back the growth production. Natural regeneration is not doing quite as well as expected. Overall, the techniques used in the form of masticate site prep and tree planting are proving successful on grass dominated sites. Wahrenbrock also plans to visit the Caribou Hills area where mounding style site prep was used to compare the treatments.

◆ **Wurtz, T.L., and Zasada, J.C., 2001.** An alternative to clear-cutting in the boreal forest of Alaska: a 27-year study of regeneration after shelterwood harvesting. Can. J. For. Res.-Rev. Can. Rech. For. 31, 999-1011.

Author abstract. We present 27-year results from a comparison of clear-cutting and shelterwood harvesting in the boreal forest of Alaska. Three patch clear-cut and three shelterwood units were harvested in 1972; about 100 dispersed white spruce (Picea glauca (Moench) Voss) leave trees per hectare were retained in the shelterwoods. Units were mechanically scarified and an exceptionally large seed-crop was dispersed that year. Shelterwood trees were removed after 15 years. After 27 years, overstory treatment had no effect on the density or growth of the species we studied, while scarification had highly significant effects. In 1999, scarified areas were densely populated with white spruce seedlings and saplings (118 000 - 129 000 stems/ha, with spruce in 100% of plots). Unscarified areas had far fewer spruce stems but were nevertheless well stocked (11 000 - 15 000 stems/ha, with 87% frequency). Initially, spruce grew best on scarified surfaces, but by 27 years, growth of the tallest spruce saplings was significantly greater on unscarified than scarified surfaces. By 27 years, cover of the grass Calamagrostis canadensis (Michx.) Nutt. had returned to preharvest levels in all treatment types. Because criteria for evaluating forest management practices have changed since this study was begun, partial overstory retention systems for the management of Alaska's boreal forest deserve further study.

◆ **Youngblood, A.P. 1990.** Effect of shelterwood removal methods on established regeneration in an Alaska white spruce stand. CJFR 20(9): 1378-1381.

Author abstract. Seedling damage during overstory removal was compared among different yarding methods; almost three times more mortality was associated with rubber-tired ground skidding than with skyline cable yarding. Seedlings ranging in height from 0.4 to 1.0 m generally received less damage or had lower mortality rates from cable yarding than did shorter or taller seedlings. Snowpack disturbance and percentage of seedling mortality were positively correlated. Results suggested that with attention to seedling height growth and yarding method,

the shelterwood regeneration system is a viable option for white spruce (*Picea glauca* (Moench) Voss) stand regeneration in interior Alaska.

◆ **Youngblood, A., and T. A. Max. 1992.** Dispersal of white spruce seed on Willow Island in interior Alaska. Portland, OR. U.S. Dept. of Agriculture, Forest Service, Pacific Northwest Research Station. RP-443. 17 pp.

Author abstract. The seasonal and spatial patterns of dispersal of white spruce (Picea glauca (Moench) Voss) seed were studied from 1986 to 1989 in floodplain stands along the Tanana River near Fairbanks, Alaska. Analysis of the 1987 crop showed that production of filled seed was strongly related to estimated production of total seed and unrelated to selected stand structural characteristics. A mathematical expression, developed to estimate dispersal of filled seed into clearcut openings, predicted dispersal between 10 and 120 meters from the edge of an opening. The pattern of wind during the seed-dispersal season was predictable and consistent with winds measured at the Fairbanks International Airport. The results give forest managers ways to increase natural regeneration of white spruce in interior Alaska.

◆ **Youngblood, A.P. and J.C. Zasada. 1991.** White spruce artificial regeneration options on river floodplains in interior Alaska. Canadian Journal of Forest Research, 21: 423-433.

Author abstract. Reforestation options for artificial regeneration of white spruce (Picea glauca (Moench) Voss) were tested on three floodplain sites near Fairbanks, Alaska. Survival of containerized seedlings after outplanting was above 96%, regardless of harvest cutting method or mechanical site preparation, and declined little between the third and fifth growing seasons. Establishment and survival after direct seeding on seed spots was more variable and differed by harvest cutting method, by type of site preparation, and by the use of plastic seed shelters for seedling protection. Maximum terminal leader growth, seedling total height, and basal diameter were found on planted seedlings in clear-cut units on the better site. In clear-cut units prepared by blading on one site, basal diameter of seedlings five seasons after outplanting was almost 50% more than on similar surfaces in shelterwood units. Planted seedlings on unscarified surfaces and in small scalped patches generally had similar basal diameters. Results suggested that similar interior Alaska floodplain forests of white spruce can be successfully regenerated by using the clear-cutting harvest method and planting nursery-reared seedlings without mechanical site preparation.

◆ **Zasada, J.C. 1990.** Developing Silvicultural Alternatives for the Boreal Forest – An Alaskan Perspective on Regeneration of White Spruce. USDA Forest Service Forest Industry Lecture Series Lecture No. 25. 44p.

Author abstract. The boreal forest is comprised of many conifer and hardwood species. One of the more difficult forest management concerns has been the regeneration of white spruce (Picea glauca) following harvesting of the extensive mixed conifer and mixed conifer-hardwood stands located in western Canada and Alaska. This paper generally describes research conducted in Alaska over about a 20-year period regarding the regeneration of white spruce and the development and testing of alternatives for natural and artificial regeneration.

◆ **Zasada, J.C. 1972.** Guidelines for obtaining natural regeneration of white spruce in Alaska USDA Forest Service PNW Forest and Range Exp. Sta. 17 pp. Portland, OR.

Author introduction. Harvesting of white spruce is currently being conducted on a limited scale in Alaska. At the present time no particular attempt is being made to regenerate these stands. However, there is a need to secure natural regeneration in these stands now and in those that will be harvested. This paper suggests a number of silvicultural treatments known to provide adequate conditions for the successful natural regeneration of white spruce and discusses some factors which must be considered in applying these treatments. The recommendations in this report are mainly the result of research conducted and experience gained in western Canada and of minimal Alaskan observations, primarily in the Tanana drainage. References to a particular subject can be found in Zasada and Gregory (1969).

Land managers should consider these recommendations a first approximation in prescribing harvesting methods, silvicultural systems, and site preparation for interior Alaska conditions. The practices prescribed in these first harvesting operations and their results must be well documented. This will allow the land manager to critically evaluate these practices and to accumulate information for refinement of the recommendations.

Some basic considerations for all timber harvesting are:

1. No practices or techniques should be prescribed which unnecessarily degrade primary land values (e.g. , soil erosion and water quality and site productivity impairment).

2. Practices which minimize the danger to adjacent, unharvested forest stands should be prescribed (e. g. , large accumulations of slash and dead or dying trees, which could be breeding sites for insects and diseases as well as creating a fire hazard, should be eliminated).

3. Forest harvesting must be considered as a management tool for obtaining regeneration as well as for the removal of the mature forest crop.

The approach used in preparing these guidelines has been to present the basic recommendations in table form. This gives the land manager a ready reference to the recommended practices. In addition, there is a brief discussion of the rationale behind the recommendations, possible means of implementing some of them, and a list of selected references.

The basic assumptions made in preparing these guidelines were:

1. White spruce can be naturally regenerated following harvesting of mature stands. Provided there is a mineral soil or similar seedbed, it is believed that there are no limitations to natural regeneration of white spruce in this part of the taiga. However, at similar latitudes in northern Finland and Scandinavia, natural regeneration is sometimes difficult and long regeneration periods are required.

2. Natural regeneration is to be relied upon in reforesting harvested or otherwise disturbed area. Under current economic conditions, this assumption is valid. However, where natural regeneration is unreliable, artificial regeneration will be required.

◆ **Zasada, J.C. and Gregory, R.A. 1969.** Regeneration of white spruce with reference to interior Alaska: a literature review. USDA Forest Service, Pacific Northwest Forest Experiment Station Research Paper PNW-79.

Author abstract. This paper reviews literature concerning natural regeneration of white spruce in the southern boreal forest and incorporates what is known about this subject for the boreal forests of interior Alaska. A mineral soil seedbed; reduction of competing vegetation; shade, especially during the first growing season; and an adequate seed supply are the four main regeneration requirements. Absence of a mineral soil seedbed appears to be the critical factor in the southern spruce forests.

◆ **Zasada, J. C.; C.W. Slaughter, C.E. Teutsch, J.D. Argyle, and W. Hill. 1987.** Winter Logging on the Tanana River Flood Plain in Interior Alaska. *Northern Journal of Applied Forestry* 4(1) 11-16.

Author abstract. Flood plains in interior Alaska support an important forest resource. Silvicultural alternatives for these sites depend on access and on the effect of timber harvesting on the residual stand and site. Some aspects (i.e., road access, logging damage to residual stand, and effect of logging on snow pack) of winter logging of white spruce on an island in the Tanana River were observed. Winter roads of snow and ice were easily developed over a variety of surface conditions and appeared to have little lasting impact. Damage to uniformly spaced residual shelterwood trees was variable. Much of this damage could be eliminated by better sale administration, methods of sale layout, and harvesting methods. Logging activity created two distinct snow layers--an upper layer mixed with logging debris and a lower, compacted layer that showed little evidence of being physically disturbed. The compacted layer could provide good physical protection to seedlings and protect the forest floor frown disturbance.

◆ **Zasada, J. C., L.A. Viereck, M.J. Foote, R.H. Parkenson, J.O. Wolff, L.A. Lankford Jr. 1981.** Natural regeneration of balsam poplar following harvesting in the Susitna Valley, Alaska. For. Chron. 57: 57-65.

Author abstract. Regeneration of balsam poplar was studied following clearcut logging with both chain saws and tractor-mounted shears in summer and winter. Logging with shears in both summer and fall resulted in the most surface disturbance and the greatest rate of poplar regeneration. Stocking averaged 29% (range 4-62%) 4 years after harvesting. Regeneration was from seeds, stump sprouts, root suckers, and buried branches. Regeneration in summer-and winter-logged sites was primarily from root suckers, but logging in the fall resulted in regeneration from buried branches. More than 50% of the stumps produced sprouts the 1st and 2d years; but after 4 years, only 15% of the stumps in the areas logged in summer still had live sprouts. Revegetation of clearcut areas was rapid and dominated by grasses, horsetails, willows, alders, and devil's club. Production of moose browse was much greater in the logged areas than in an unlogged control. Limiting clearcutting to summer and encouraging disturbance of the surface could increase poplar regeneration.

Section 4
SITE PREPARATION, COMPETITION CONTROL, AND SOILS

SUMMARY

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Site preparation activities are designed to expose mineral soil and retard the spread of competing vegetation until young trees can prevail. Site preparation methods include burning, mechanical scarification and herbicides. Each method has variations that have been tested in various conditions prior to seeding or planting. Site preparation success is measured by regeneration survival, growth of desired seedlings, and suppression of competing vegetation.

Site preparation is often necessary to improve natural or artificial regeneration of spruce and birch—two important commercial tree species in Interior and Southcentral Alaska. Collins et al. (1998, see Wildlife, section 6) states that harvesting spruce or birch without sufficiently disturbing the forest floor often results in grass establishment that will persist for many years, inhibiting young tree growth. Schulz (1999, see Silvics, section 2) concluded that site preparation and artificial regeneration are the only effective means of establishing forest communities in the absence of natural regeneration. On Kenai Peninsula sites where virtually all sexually mature spruce died during the beetle infestation, site preparation and artificial regeneration, appear to be the only means of regenerating spruce stands, given the lack of seed source anticipated for several years until residual spruce yield viable seed. Site preparation may not be needed where sites lack advanced herbaceous competition and have abundant residual trees. Collins (1996, see Wildlife, section 6) notes that that for birch, clear cutting with retention of seed trees is a viable alternative to burning on mesic and dry sites providing harvest and scarification is completed within one year before competing ground cover could exclude hardwood seedling establishment.

Mechanical scarification is the most broadly used site preparation approach in Alaska. Scarification prescriptions require varying amounts of ground disturbance, and use several different types of equipment. Boateng, et al. 2006 explored the effects of six mechanical site preparation methods on planted spruce over a 20-year period. Of particular interest to Alaska are the comparisons between mounding and other blading scarification techniques. In 2011, mounding was implemented prior to planting on sites heavily occupied by grass in the Caribou Hills. In 2014, Wade Wahrenbrock (pers. comm.) inspected the sites and was impressed by the seedlings thriving in the mounded soil. Further surveys are being considered to more accurately measure the effectiveness of mounding.

It is often assumed that summer logging operations provide sufficient ground disturbance for site preparation as tracks and wheels incidentally grind the organic mat and expose mineral soil.

However, Marquis and Bjorkbom (1960) contend that this does not provide sufficient site disturbance for regenerating birch. Additional scarification applied uniformly is necessary.

Broadcast burning for site preparation is difficult in Alaska. Fuel and weather conditions must be warm and dry to achieve an intense burn that will control competing vegetation. Under these conditions, fires are difficult to control and fire control resources are limited.

Herbicides have been used in commercial forest operations on some private land in Alaska. Herbicide applications are governed by AS 41.17.100 and 18 AAC 90. Newton (1997) evaluated the effectiveness and environmental impacts of glyphosate, hexazinone, and triclopyr in both coastal and interior Alaska.

Bluejoint reedgrass (*Calamagrostis canadensis)* is the most problematic species competing against regeneration in Regions II and III. After logging, low-intensity fires, or other disturbances, *Calamagrostis* propagates quickly, forming a complete stand with a thick layer of thatch that restricts establishment of other species. *Calamagrostis* regenerates principally by rhizomes that are invigorated with minor disturbances (Darris 2005). Lieffers et al. (1993) assesses mechanical, herbicide, and fire options for *Calamagrostis* control. Bella, E.M. (2013) studied the effects of controlling *Calamagrostis* by mowing, masticating, herbicides and burning. Mowing and masticating the two methods most likely to be applied, particularly where there are public, agency, or land management concerns regarding fire or herbicides. Lieffers, et al. (1993) discusses the need for scalping or mounding microsites for planted seedlings on sites colonized by *C. canadensis*. This study also concluded that shade from partial canopies inhibits grass spread. Minimizing surface disturbance will enable residual seedlings to thrive while the shade keeps grass spread in check. This practice would be useful to consider for partial cutting with natural regeneration. Gartner, et al. (2011) and Smith (1988) also address mounding in site preparation include

Other references that assess *Calamagrostis* competition and control include Darris (2005), Macey and Winder (2001), Graham and Wurtz (2003, see Methods, section 3), Jandreau and Arians (2006, see Methods, section 3), Lieffers and Stadt (1994, see Silvics, section 2), Newton (1996, see Methods, section 3), Packee (2001, see Methods, section 3), Wurtz and Zasada (2001, see Methods, section 3), Boucher (2003, see Fire, section 5), Cater (1990, see Fire, section 5), and Holsten et al. (1995, see Insects and Disease, section 7).

Maisch et al. (2001, see Methods, section 3) concluded that site preparation would benefit spruce regeneration, and is recommended for natural regeneration. Site preparation and planting is less expensive and more effective if carried out immediately after forest disturbance.

REFERENCES

◆ **Arikian, M.J., K.J. Puettmann, A.L. Davis, G.E. Host, George E., J. Zasada. 1999.** Harvesting impacts on soil properties and tree regeneration in pure and mixed aspen stands. Conference Proceedings. p. 329-331

Author abstract. Impacts of clearcutting and selective harvesting on pure aspen/mixed aspen hardwood stands were examined in northern Minnesota. We studied these impacts on 18 stands, which were harvested 4 to 11 years ago and received no further treatment. In each stand, residual composition, soil compaction, and tree regeneration were determined along a gradient of disturbance in the summer of 1998. This preliminary assessment investigates interacting effects of soil compaction, residual overstory conditions, and timing of harvests. Compaction levels were much more variable in areas that were harvested in summer rather than in winter. Stands harvested in the winter were associated with higher regeneration stem densities and height growth than those harvested in the summer. Tree regeneration stem densities and height growth decreased with increasing soil compaction and increasing residual basal area. These results show the importance of understanding complex interactions between pre-harvest and post-harvest conditions, harvesting disturbance, and soil properties as they determine future stand composition and productivity.

◆ **Bella, E.M., 2013.** *Calamagrostis Canadensis* treatment plots vegetation summary. Unpublished report.

Author abstract. Vegetation cover and structure was measured in five plots in each of three bluejoint reedgrass (*Calamagrostis canadensis* L.) treatment plot sites (Griner, Mile 149, Kenai) on the western Kenai Peninsula on August 1st, 2013. Plots were circular one meter area plots, set up with a center stake and a measured flexible string perimeter. The purpose was to assess effectiveness of bluejoint reedgrass control types by examining general vegetation composition within each of the five different treatments (weed whacker, T1; mower, T2, masticate, T3, herbicide, T9; and herbicide & burn, T12) and to potentially detect any differences in vegetation composition and structure between treatments and sites. Percent of ground cover was measured within each plot, in five categories. Percent by life form and percent cover by species was also measured within each plot, and are referred to as environmental parameters.

◆ **Boateng, J.O., J.L. Heineman, L. Bedford, G. J. Harper, and A.F.L. Nemec. 2009.** Long-term effects of site preparation and postplanting vegetation control on Picea glauca survival, growth and predicted yield in boreal British Columbia. Scandinavian Journal of Forest Research 24:111-129.

Author abstract. The 19-20 year effects of mechanical site preparation, windrow burning, chemical site preparation, and post planting vegetation control on survival and growth of planted white spruce are reported from two boreal sites in British Columbia, Canada. Survival differed between treatments at both sites, but was relatively good (≥77%) even in untreated plots. Current data regarding the proportion of spruce that were physically overtopped by vegetation and previous results from related soils and vegetation studies suggest that lasting reductions in tall shrub and aspen abundance were more important to spruce growth than early micro-environmental effects associated with manipulating the rooting environment. At Inga Lake, post planting vegetation control produced a 13-fold increase in spruce volume over the control after 19 years, which was statistically equivalent to increases resulting from fine mixing, plow-inverting and windrow burning site preparation treatments. At Iron Creek, chemical site preparation and plow-inverting quadrupled spruce volume, whereas mounding, patch scarification and disc trenching were ineffective. Growth and yield simulations using treatment-specific site index curves for Inga Lake suggested that rotation length could be shortened by 12-16 years through the use of site preparation or post planting vegetation control. However, untreated areas, due to the relatively good survival of white spruce at age 19, were predicted to produce equivalent volume if left to grow to mean annual increment culmination age.

◆ **Boateng, J.O., J.L. Heineman, J. McClarnon, and L. Bedford. 2006.** Twenty year responses of white spruce to mechanical site preparation and early chemical release in the boreal region of northeastern British Columbia. Canadian Journal of Forest Research, 36: 2386-2399.

Author abstract. The effects of six mechanical site preparation treatments, two stock-type treatments, and early chemical release on survival and growth of planted white spruce (*Picea glauca* (Moench) Voss) were studied in the BWBSmw1 biogeoclimatic zone of northeastern British Columbia. After 20 years, spruce height and diameter were larger in all mounding treatments than in the control. Early results suggested better spruce performance on large than small mounds, but after 20 years, growth was equally good on small mounds as on mounds with 20 cm mineral capping. Spruce planted on hinge positions in the Bräcke patch and blade scarification treatments did not survive or grow well. Early chemical release improved spruce growth equally as well as the mounding treatments. Twenty year spruce survival averaged 71% in the 14 and 20 cm mound treatments, 60% in the early chemical release treatment, and ≤35% in the Bräcke patch and blade scarification treatments. A large stock type was also planted in untreated ground and, after 20 years, had similar survival and growth as the standard stock type. Differences in survival had a large effect on basal area at age 20 years. Trend analysis showed that treatments diverged into two distinct groups with regard to spruce size during the 20 year span of the study.

◆ **Collins, W.B. 2001.** Heavy Grazing of Canadian Bluejoint to Enhance Hardwood and White Spruce Regeneration. North. J. Appl. For. 18(I): 19-21.

Author abstract. Wet, disclimax stands of Canadian bluejoint (Calamagrostis canadensis {Mic/u:.] Beauv.) created by logging were heavily grazed by cattle and horses years 5 through 8 after logging to weaken the grass and favor regeneration of hardwoods and white spruce (Picea glauca {Moench.) Voss). Seedling densities of hardwoods and white spmce in heavily grazed stands were not significantly different ($P < 0.05$)/rom those in ufngrazed stands. Heavy grazing reduced herbaceous cover and litter but was not detrimental to runoff water quality. Heavy grazing was not effective for increasing regeneration in wet disclimax stands of Canadian bluejoint where the grass had already increased following overstory removal, but earlier application and use in drier sites should be considered.

◆ **Collins, W.B., E.F. Becker, and A.B. Collins. 2001a.** Canadian bluejoint response to heavy grazing. J. Range Manage. 54: 279-283 May 2001

Author abstract. A disclimax stand of Canadian bluejoint (Calamagrostis canadensis (Michx.) Beauv.) was heavily grazed by cattle and horses for 4 years to weaken the grass's competition with hardwoods important as browse and cover to wildlife. Stocking at 0.084 ha AUM-l resulted in uniform utilization of bluejoint and maintenance of early phenology through the growing season. Etiolated bluejoint declined about 90%, but grass production increased 10 to 15%, as fireweed (Epilobium angustifolium L.), a principal herbaceous component of the stand, decreased in response to trampling. Rhizomes of heavily grazed bluejoint had lower total nonstructural carbohydrates (TNC) (p = 0.0127), lower weight (g cm-' length) (p = 0.05), and reduced biomass (g cm-3 of soil) (p = 0.05). Shoots of grazed bluejoint maintained higher nitrogen (p = 0.0001) and higher digestibility (IVDMD) (p = 0.0017) than bluejoint that was never grazed. This enabled heavily grazed bluejoint to retain good forage quality through the entire growing season, as opposed to ungrazed bluejoint, which became poor forage at the time of flowering during early July. Following one season of rest, rhizome TNC, shoot nitrogen, and IVDMD returned to levels of never grazed bluejoint. Seedhead production, seed production, seed weights, and seed viability of rested bluejoint were about the same as in ungrazed stands. On wet sites, heavy grazing does not adequately reduce the vigor of this grass.

◆ **Converse, C.M. 1999.** Mechanical site preparation and tree planting equipment for Alaska. pp. 57-67 in: Proc. of the Alaska Reforestation Council April 29, 1999 Workshop. Anchorage, AK. Univ. of Alaska Fairbanks Agric. & For. Exp. Sta. Misc. Publ. 99-8. 85 pp.

Author abstract. Regeneration success depends on site preparation and proper seedling handling and planting techniques. Mechanical blade, brush, and rock rakes scarify sites satisfactorily for both natural regeneration and hand planting. Roller Nose V-plows prevent soil gouging and are recommended site preparation attachments for machine planting. Taylor, Whitfield, and double-row Hoedag Planting Machines should be successful on favorable sites in Alaska.

◆ **Crossley, D. I. 1956.** Mechanical scarification and strip clear-cutting to induce lodgepole pine regeneration . Canada Dept. of Northern Affairs and Natural Resources. Forestry Branch, Forest Research Division. Tech. Note. No. 34. 14 pp.

Author abstract. Lodgepole pine *(Pinus contorta Dougl. var. latifolia Engelm.)* is recognized as a fire type that regenerates readily after the humus has been destroyed by fire and seed released from the serotinous cones opened by heat. However, a very wide variation in stocking is the usual result. From a study of the causes of variation in stocking on a large regenerated 16-year-old burn on the Kananaskis Forest Experiment Station in Alberta, Horton (1953) found that 25 per cent of the area was heavily overstocked and stagnating, and an additional 23 per cent was lightly overstocked and would probably stagnate in the future. He concluded that the usual tendency after fire was toward overstocking on the better sites. Stagnation in lodgepole pine stands is a difficult condition for the silviculturist to overcome and the best defence against it appears to be the prevention of over-abundant regeneration. Apparently this precludes the use of fire, at least under natural conditions. Clearcutting on the Lewis and Clark National Forest in Montana (Anon. 1950) resulted in good regeneration of lodgepole pine both on the untreated forest floor and on the skid roads, with heavy slash inhibiting reproduction, and broadcast burning greatly curtailing it. Clearcutting in strips on the Kananaskis Forest Experiment Station, with piled slash, resulted in adequate but not superabundant regeneration (Crossley 1952), but success was credited to a poor site as reflected in a light surface litter and a scarcity of competing vegetation. Whether similar results could be obtained on better sites in Alberta where the duff is heavier than in Montana and where competition from more luxuriant ground vegetation becomes an important factor remained to be proved. Eyre and Lebarron (1944) were unable to regenerate jack pine adequately without baring the mineral soil to seed fall and they accomplished this by mechanical means. It is obvious when clearcutting in lodgepole pine stands that the seed to regenerate the site must come from one or both of the following sources: (1) from the serotinous cones in the slash, or (2) from the seed supply in the cones of the marginal stands. Contrary to the popularly accepted belief, not all lodgepole pine trees bear their cones serotinously, nor are all cones on any one tree necessarily serotinous. Studies presently under way in Alberta (Crossley 1955) indicate that there is a light but continuous seed release from natural pine stands which reaches a maximum at the time of cone ripening in September each year. The present study was designed to investigate the receptivity of the forest floor to lodgepole pine regeneration after strip clearcutting when mechanical scarification had bared the mineral soil, in comparison with the forest floor not specifically treated, each to be subjected to a seed supply from: (a) the marginal stands, and (b) marginal stands and the lopped and scattered slash.

◆ **Crossley, D.I. 1955.** Survival of white spruce reproduction resulting from various methods of forest soil scarification. 1955. Crossley, D.I. Government of Canada, Department of Northern Affairs and National Resources, Forestry Branch. Forest Research Division Technical Note 10. 10 pp.

Author summary. A study was undertaken on the Kananaskis Forest Experiment Station, Alberta, to investigate the effect of fire and of certain mechanical equipment in the preparation of seed-beds receptive to white spruce reproduction on inadequately restocked cut-over areas. Soils were scarified by 11 different methods during the summer of 1948. An initial report based on two years data was prepared and published (Crossley, 1952). The present publication is based on three years additional data, and reports that all methods of soil treatment under study have proven more effective than the untouched control, that several of them satisfy even the most demanding stocking requirements, and that certain degrees of improved receptivity are still evident five years after treatment. In addition it is apparent that loss of seed prior to germination is a factor of major importance, and that seed crop evaluation is intimately connected with choice of seed-bed treatment. The investigation will continue.

◆ **Curran, M.P. and Ballard, T.M. 1990.** Some slash burning effects on soil and trees in British Columbia. In: Gessel, S.P., Lacate, D.S., Wetman, G.F., Powers, R.F. (Eds.). Proceedings of the 7th North American Forest Soils Conference, University of British Columbia, Vancouver, BC, Canada. July 1988 Faculty of Forestry, University of British Columbis, Vancouver, BC, Canada. Pp. 355-361.

Abstract not currently available

◆ **Dyrness, C. T., L.A. Viereck, M.J. Foote, J.C. Zasada. 1988.** The Effect on vegetation and soil temperature of logging flood-plain white spruce . USDA Forest Service Res. Pap. PNW-RP-392. Portland, OR. 51 pp.

Author abstract. During winter 1982-83, five silvicultural treatments were applied on Willow Island (near Fairbanks, Alaska): two types of shelterwood cuttings, a clearcutting, a clearcutting with broadcast slash burning, and a thinning. The effects of these treatments on vegetation, soil temperature, and frost depth were followed from 1983 through 1985. In 1984 and 1985, logged plots had significantly higher soil temperatures than did the controls; clearcut and burned sites had the greatest increases. Vegetation composition was profoundly changed on the clearcut and burned units and altered to a lesser extent on the units receiving the other treatments.

◆ **Haugo, R.D., J.D. Bakker, and C.B. Halpern. 2013.** Role of biotic interactions in regulating conifer invasion of grasslands. Forest Ecology and Management 289: 175–182. [L]

Author abstract. Woody-plant invasions can be regulated by positive and negative interactions with the recipient community, but the sensitivity of these interactions to ontogeny or abiotic conditions is not well understood. We experimentally examined germination, seedling survival and growth of the conifer, *Pseudotsuga menziesii*, in response to above- and below-ground interactions with resident vegetation in low-elevation prairies of western Washington (USA). Shading, below-ground competition, and soil origin (prairie vs. forest) had strong and, at times, interacting effects on *Pseudotsuga* establishment. These effects varied among life stages and years. Germination was strongly enhanced by shading and inhibited by below-ground competition during a drought year, but not during a wet year. Germinant and seedling survival were strongly enhanced by shading, inhibited by below-ground competition, and unaffected by forest soil or mycorrhizal inoculation. Seedling growth was strongly negatively affected by below-ground competition, weakly affected by soil origin, and unaffected by shading. No individuals survived a single growing season in the absence of shade and presence of competing vegetation. In contrast, the presence of shade and removal of below-ground competition increased mean survival to _85%. Our results demonstrate that biotic factors can regulate woody-plant invasions and that the strength and direction of these effects can differ with ontogeny and abiotic conditions. Although woody-plant invasions are typically attributed to extrinsic factors (e.g., climate, fire, or grazing), our results highlight the importance of biotic interactions as critical intrinsic controls.

Notes. Study was conducted in Puget Sound region of western Washington with a focus on Douglas-fir invasion.

◆ **Hunt, J. A. 1988.** Mechanical site preparation and forest regeneration in Sweden and Finland: implications for technology transfer . Canadian For. Service. FRDA Report, Volume 26, Issue 3.

Author abstract. Swedish and Finnish (Fennoscandian) mechanical site preparation experience is extensive. An understanding of its evolution should benefit development of site preparation in Canada. Since site preparation is just one component of forest regeneration, which in turn is integrally related to the whole process of forest management, a technical study of site preparation was thought to be insufficient without some discussion of silviculture in Fennoscandia. This report, therefore, describes some trends in Fennoscandian silviculture, and mechanical site preparation and reforestation techniques. Implications for the transfer of this technology to British Columbia are also discussed.

◆ **Lees, J.C. 1963.** Partial cutting with scarification in Alberta spruce-aspen stands. Ottawa, [Ont.]: Dept. of Forestry, Forest Research Branch, 1963. Dept. of Forestry publication ; no. 1001

Author abstract. In 1952, a study was begun in 110-year-old spruce-aspen stands in the B-18a section of Alberta's mixed-wood to investigate scarification for white spruce regeneration before and after partial cutting to four residual stand densities: a) control, b) heavy, c) medium, and d) light.

Scarification was carried out using a TD9 tractor with a 9-foot straight blade. Three seedbed types were compared: a) scarified, b) mounded, and c) undisturbed.

Germination and survival of spruce seedlings were tallied on subsamples of 4,000 quarter milliacre quadrats between June 1956 and November 1957 and 400 scarified quadrats in 1959. Windfall and mortality, and residual stand growth, were measured in 1959 on 40 half-acre plots.

It was found that:--

a) Only the scarified seedbed permitted satisfactory establishment of spruce regeneration and remained receptive for five years.

b) Regeneration establishment was not affected significantly by residual stand density or time of scarification.

c) Mortality and windfall were slight, occurring mainly in stems damaged by either scarification or logging.

d) Growth rates for spruce were good considering the age of the stands, and a valuable recruitment to the merchantable size class (7 inches d.b.h.) was noted.

e) The success of partial cutting with scarification is sufficient to recommend its further use in the Mixed-wood Section.

◆ **Lieffers, V.J., S.E. Macdonald, and E.H. Hogg.. 1993.** Ecology of and control strategies for *Calamagrostis canadensis* in boreal forest sites. Canadian Journal of Forest Research 23(10): 2070-2077. 10.1139/x93-258.

Author abstract: *Calamagrostis canadensis* (Michx.) Beauv. Is a widely distributed rhizomatous grass that can seriously inhibit growth of white spruce (Picea glauca (Moench) Voss) seedlings in the boreal forests of North America. We review the dynamics of this grass during four successional stages: the colonization of disturbed sites; dominance of the site by the grass a few years after disturbance; gradual loss of dominance with overstory development; and maintenance of the grass at low levels in the understory of mature forest. We also describe *C. Canadensis* in relation to recruitment from clonal growth and seed environmental conditions for growth, the effects of grass litter buildup on conifer seedling microclimate, and overall competitive abilities. Control strategies for *C. Canadensis* are as follows. If the grass is found in nearly every square meter in the understory prior to logging, there will be rapid spread when the stand is clear-cut unless clones are killed using herbicides or a deep burn. Large spruce seedlings, planted on large soils scalps or mounds, coupled with release by way of herbicides or sheep grazing, may be necessary for plantation establishment under conditions of encroachment by *C. Canadensis*. Alternatively, the shade provided by a partial canopy may inhibit the grass sufficiently to allow spruce seedlings to establish. If grass is not abundant in the understory, we recommend (i) minimizing forest floor disturbance to reduce sites for grass seedling colonization or (ii) a slash burn with the hope of encouraging colonization by herbaceous species that have less impact on conifer seedlings.

◆ **Lofroth, E. 1998.** The dead wood cycle. Pages 185-214 *in* J. Voller and S. Harrison, editors. Conservation biology principles for forested landscapes. University of British Columbia Press, Vancouver. 233 p. [M]

Compiler abstract. This chapter begins with definitions and then describes the dynamics of dead wood cycles and their ecological roles for snags (standing dead, >10 cm dbh, >2 m tall, >45 degree angle of repose from the ground), coarse woody debris (>10 cm diameter and <45 degrees above the ground, terrestrial), and large organic debris (>10 cm diameter, aquatic) of British Columbia. Interior and coastal forest types are not specified directly in most instances, but primary sources are cited that would permit inference on forest type. Broad management recommendations and research needs are given.

The role of coarse woody debris in nutritent cycling is reviewed, and it is noted that "dead wood in terrestrial ecocystems is a primary location for fungal colonization and often acts as refugia for mycorrhizal fungi during ecosystem disturbance" (p. 206).

◆ **Lyon, N. F. 1977.** White spruce seed tree system with mechanical seedbed preparation . Ontario : Ministry of Natural Resources, Silvicultural Note #15. 15 pp.

Author introduction. Tree planting, to regenerate white spruce *(Picea glauca* (Moench) Voss) on harvested areas, is currently conventional but is expensive and not always successful. An alternative to plating for areas including in current cutting plans is a modified clearcut involving the leaving of white spruce seed trees combined with mechanical seedbed preparation. The system has been tried with varying degrees of success on a limited operational basis in a number of areas in northern Ontario. Significant gains in the white spruce content of 2000-9000 established stems per acre (approx. 4900-22,000 per hectare at stockings ranging from 55 to 85 percent have been obtained in research trials. On the net treatment portion of these trials densities over the range of 4000-15,000 stems per acre (approx., 9800-37,000/ha) with stockings of 70 to 95 percent were obtained (Lyon 1968). In one specialized forest management area where the objective was to create a natural white spruce seed production area by applying some of the principles of the seed tree system, densities in excess of 10,000 stems per acres (approx. 25,000.ha) were obtained (Skeates 1961, Jovic 1972).

The seed tree system demands more advanced planning, field inspection and procedural consideration s than do the conventional reforestation techniques. Before harvesting, the soil and stand characteristics must be examined to determine the suitability of the area for the system. The seed trees must be carefully selected and reserved from cutting. A seed year must be ascertained before seedbed preparation is carried out. The seedbed treatment must be carried out in advance of seed fall.

While the success of the system is directly related to a number of interlocking factors its fundamental consideration is that if there is no natural white spruce seed source left on the harvested area then there will be no additional natural white spruce regeneration.

The success of the system is also based on the need for the forest manager to have a known or desired forest objective, i.e., a predetermined visualization of the white spruce component in the forest wanted. The objective must be established by prior consideration of the whole range of management and species working group objectives and regeneration alternatives available.

This silvicultural note is intended as a short summary of the most important facets for using this regeneration system. The recommendations are based on observations and experience obtained in operational trials as well as on reviews of pertinent literature. As described here the system is designed and recommended as a post-harvest regeneration treatment provided that the necessary pre-harvest reservations have been made. If necessary and with some modifications, particularly in machine size and manoeuverability and in some aspects of competition control, the system could be undertaken as a pre-harvest regeneration system.

It is planned that his note be amended as and where additional information is obtained from more operational usage of the system.

◆ **Macey, D.E. and R. S. Winder. 2001.** Biological Control and the Management of *Calamagrostis canadensis* (Bluejoint Grass). Canadian Forest Service, Forestry Research Applications, Pacific Forestry Center. Technology Transfer Note 25. 6 pp.

Compiler abstract. This article reviews control options for *Calamagrostis canadensis* following harvest. It briefly summarizes pros and cons of chemical herbicides, prescribed burning, mechanical site preparation, manual grass cutting, sheep grazing, and mulch mats. The authors note that practices that reduce grass growth are often preferable to eradication, and they discuss planting herbaceous plants that compete with grass, conducting partial harvests, planting larger tree seedlings, and increasing stocking densities. The article covers biological control options in more depth, including research on fungal pathogens, deleterious rhizosphere bacteria (DRB), and combinations of the two. In greenhouse tests, both pathogens and DRB showed promise for reducing grass competition, but were most effective used in combination. These treatments did not cause foliar or root damage nor affect growth of white spruce, lodgepole pine, or trembling aspen seedlings.

The authors state that it is important for forest managers to recognize the threat of *C. canadensis* invasion prior to harvest, and incorporate practices that minimize invasions and control grass spread into silvicultural prescriptions. Partial cutting could reduce the risk of serious infestation. Practices that mix the soil encourage grass rhizome sprouting and germination of buried seed, as does light burning. Immediate planting following disturbance using large caliper stock and higher than minimum stocking densities is a major defense against infestation.

Although no biologicals are currently registered for use in forestry, an integrated strategy that combines biological control with low-impact silvicultural techniques is envisioned. A strategy to proactively control infestations before they begin will be most successful at reducing plantation failure and increasing tree productivity in areas of high risk for grass invasion.

◆ **M.D. MacKenzie, M.G. Schmidt, and L. Bedford. 2005.** Soil microclimate and nitrogen availability 10 years after mechanical site preparation in northern British Columbia. Canadian Journal of Forest Research 35: 1854–1866. doi: 10.1139/X05-127

Abstract: Mechanical site preparation (MSP) changes the distribution and character of forest floor and mineral soil and may affect soil nutrient availability, soil water content, and soil temperature. The effects of different kinds of MSP were compared to a control in the tenth growing season at two research sites in northern British Columbia. To compare MSP results with those of the natural disturbance regime, a burned windrow treatment was also included in the analysis. The bedding plow, fire, and madge treatments all had significantly greater crop-tree growth compared to the control. The bedding plow and madge treatments had significantly lower soil bulk density, higher soil temperature, and lower soil water throughout the growing season compared with that of the control. The bedding plow also resulted in significantly higher concentrations of total carbon, total nitrogen, NH4+, and NO3– than that of the control, at both the 0–10 and 10–20 cm depths. The madge rotoclear resulted in significantly greater potential mineralizable N than that of the control. Ionic resins bags, installed for one growing season, did not show any significant treatment differences in available soil nitrogen. MSP did not reduce soil fertility on these sites when compared with an untreated control, but it is difficult to say that it improved it.

◆ **Maini, J. S. and K.W. Horton. 1966.** Reproductive response of Populus and associated Pteridium to cutting, burning and scarification . Canada. Dept. of Forestry and Rural Development) ; no. 1155.

Introduction. *Populus tremuloides* Michx. And *P. grandidentata* Michx. (aspens), taxonomically and silviculturally closely related species, are gaining economic importance in North America. Whereas natural regeneration of these two species is negligible in undisturbed stands, abundant root suckering generally occurs when aspen stands are subjected to cutting, burning and other disturbances. According to Maini (1960) and Maini and Horton (1966) an insolation-induced thermal increase usually plays a critical role in sucker initiation. Management of aspen stands, either for the propagation of aspen or for conversion to some other desirable species required judicious application of various cultural treatments. The present investigation was conducted during 1962 in southern Ontario to appraise the relative effects of cutting, burning and ground scarification treatments on the regeneration of *P. tremuloides, P. grandidentata* and associated ground vegetation , particularly *Pteridium aquilinum* (L.) Kuhn (bracken). The influence of these treatments on the heat economic the upper soil layers was also evaluated.

The significance in the timing of cutting aspen stands has been discussed by Baker (1918) and Stoeckeler and Macon (1956). Dormant-season cutting produces initially more vigorous toot sucker regeneration than summer cutting because in the latter, suckers emerge when the reserve food material in the roots is presumably low and competition by associated ground vegetation is intensive. The later the suckers appear during the growing season, the poorer is their development. However, after a lapse of two years, sucker density was similar in summer-cut and winter-cut stands (Sandberg and Schneider 1953).

Scarification by discing has been found effective for inducing aspen suckering in under-stocked stands (Zillgitt 1951) and in stands where cull trees have been left standing (Zehngraff 1949). Also, following fire in a *Populus* stand, development of a dense sucker crop is usual. An increase in number and vigour of suckers was observed when heavily cut areas were lightly burnt (Shirley 1931, 1932). Repeated burning also stimulated suckering (Shirley 1941).

*Suckering response of as*pen to the above cultural treatments is effected internally or externally, and it is impossible to separate the two. Among the internal influences, sucker formation may result from injuries inflicted on stems and roots by cutting, scarification or burning, which upset the internal metabolic balance. However, the same disturbances have important external effects—the thermal, hydrological and nutrient conditions may be significantly altered by removing trees, ground vegetation and loose litter, by burning organic matter, as well as by disturbing and loosening superficial soil layers. The present study attempts to separate these causative factors and to determine their relative effects on reproduction of aspen and associated bracken.

◆ **Marquis, D.A. and J.C. Bjorkbom. 1960.** How much scarification from summer logging. USDA Forest Service, Northeastern Forest Exp. Sta. Forest Research Note NE-110. Upper Darby, PA.

Author abstract. Scarification of the soil creates seedbeds that are favorable for the establishment of both paper birch and yellow birch. Logging in the summer often has been recommended as a method of obtaining these seedbeds. However, our observations on experimental logging jobs have shown that logging alone does not provide scarification over enough of the area to assure reasonably uniform distribution of birch regeneration.

◆ **Newton, M. 1997.** Reforestation and vegetation in central Alaska. U.S. Dept. of Agriculture, Forest Service, Alaska Region, 1997. Special report R-10-TP. 80 pp.

Author summary. The three following papers summarize nine years of research of Oregon State University, Department of Forest Science relating to the principal technical obstacles to artificial regeneration in south-central and interior Alaska. The key elements include 1) determination of severity of plant competition and consequences of not weeding in the first five years of spruce plantations, 2) comparisons of methods of controlling competition, and 3) evaluation of environmental impacts of the various methods of vegetation control. We also address preliminary findings on importance of the size of planting stock after various forms of mechanical and chemical site preparation.

Plant competition in the forms of grass, fireweed, aspen, and other overtopping species severely reduces growth and survival of interior white spruce. Allowing vegetation to become established before planting leads to sharply poorer post-planting performance expressed as volume growth. Trees planted in established cover that is chemically controlled grow significantly more slowly than when planted in new clearcuts receiving apparently analogous degree of control. That is, it takes less cover to slow spruce growth in a 3-yer-old clearcut than in a new unit when all other conditions are the same. Seedlings grow twice as fast in the new clearcut than the old in the same ranges of cover. If the clearcut is freshly burned, seedlings grew twice as rapidly as in the new, unburned soil, cover for cover. In all types of harvest unit, speed of overcoming white spruce “planting check” was positively related to degree of freedom from competing cover. With competition–free plantings, height growth was approaching the same rate for all three types of unite (burned, new clearcut, 3-year-old cut), but methods of weeding other than annual chemical maintenance varied in efficacy according to weed cover at the time of planting; more cover reduced efficacy in general. This was observed near Fairbanks and also at Ft. Richardson. Patterns were very consistent for the two sites and different years of planting.

Mortality of planted spruce was affected principally by two factors. Overtopping was a major cause but often required several years to cause death. Very early several freezing (15° Sept. 8, 1993) caused mortality on Fairbanks experiments that were nearly competition-free, and were late-flushing. That was an extreme event, repetition of which is very rare, hence we discount freezing as a major risk of weeding.

Paper birch plantings responded to competition much as did white spruce. Unlike spruce, browsing by moose at Ft. Richardson all but eliminated differences in heights for various levels of competition, but weed-free birch developed much more stem volume and biomass. Freezing damage is a major cause of mortality in all treatments on sites with cold-air drainage.

When comparisons of planting stock types were done after four different methods of site preparation, plug-1 transplants were 2-4 times as large in year 3 as either of two commercial 1-0 plug types on sites treated with glyphosate plus hexazinone before planting. This site prep method was significantly more effective than spot spraying, mechanical clearing, or fresh logging alone. In all methods of site preparation, the plug-1's grew 2-4 times faster in terms of absolute growth than other stock types by year 3.

Efficacy of methods for controlling vegetation to meet seedling needs is very similar to findings in the Douglas-fir region. Glyphosate, imazapyr, and triclopyr may be used at rates that cause negligible harm to spruce, yet will kill most herbs and deciduous shrubs at chemical cost of <$50/ac plu application. Glyphosate is effective on most of Alaska's competitors for <$30/ac alone, but has no residual effect. Hand scalping and hand brushing may provide for confer establishment in grass or alder cover, but hand scalping of grass was difficult. Mechanical methods are feasible for favoring moose browse. Details of all treatments are given.

Environmental impacts of chemical methods were evaluated in terms of persistence and mobility of chemical residues in vegetation and soils. Residues in vegetation were completely dissipated for glyphosate, imazapyr, hexazinone, and triclopyr within one year on a coastal site (windy Bay), and triclopyr persisted slightly longer al low levels near Fairbanks. Mobility in soil was low, with no more than 30% of an initial deposit in the surface soil moving below 6". Persistence in Alaska was comparable to growing season environments in the lower 48 states. Half-lives in the summer environments range from estimates of 25 to 120 days for the four products, with hexazinone the only one over about 50 days. No dissipation occurred or was expected in winter. All products were non-detectable by 410 days after treatment in all locations.

All four products evaluated are low in toxicity, and difficult of impossible to dislodge from the field environment unless freshly treated vegetation is contacted. Vegetation residues were all within the range of concentration producing no observable effects in test animals. Hexazinone moved off-site in water on large plots treated for evaluation of worst-case conditions. Whereas 7% of the applied hexazinone appeared to have left these sites under intensive rain events, concentrations are unlikely to reach detectable quantities in fish-bearing streams in basins with 5% of the entire basin receiving treatment.

Mechanical or manual controls of vegetation have inherently higher environmental impacts than herbicides in terms of total energy use, total chemical use and potential for causing stream pollution with silt or fuel. They also seldom provide extended control of vegetation in sufficient degrees to enhance over-all reforestation efforts at acceptable costs.

◆ **Norman, C.M. 1978.** Ripper scarification: A silvicultural technique developed in northwestern Alberta. The Forestry Chronicle. 54(1): 15-19, 10.5558/tfc54015-1

Author abstract. There are currently several different scarification techniques being applied silviculturally in Alberta. All techniques are designed around a crawler tractor equipped with a front-mounted dozer or ripper blade. Although these techniques are effective on better drained sites, their efficiency is limited on wet or frozen ground. Summer is the most suitable time for general reforestation operations but is often a very poor time for good forest access and site operability in low wet areas. These considerations in mind, North Canadian Forest Industries Limited, Grande Prairie, determined the most economical time to carry out its scarification would be in winter when access is best and winter logging is in full scale operation. A parallelogram ripper mounted on the rear of a suitably sized crawler tractor has proven to be best suited for this heavy work. Equipment was designed, modified and built for use on the parallelogram ripper. Three thousand acres (1200 hectares) have been treated to date at a very reasonable cost, many of these acres being virtually untreatable during the summer or winter by conventional means.

◆ **Packee, E. C. 1990.** White spruce regeneration on a blade-scarified Alaskan loess soil. Northern Journal of Applied Forestry 7:121-123.

Author abstract. Following hardwood removal from a mixed spruce-birch-aspen forest stand, portions of the stand were blade-scarified to encourage natural white spruce regeneration. Six years after treatment the number and height of white spruce seedlings were significantly greater on scarified than on unscarified plots. Whereas 100% of scarified sample plots contained five or more seedlings, 73% of unscarified plots contained no seedlings. Exposure of mineral soil and removal of grass competition are essential for the satisfactory natural regeneration of white spruce. Detailed regeneration surveys should not be considered for white spruce until seedlings are 15 cm tall, typically the fifth or sixth year after site preparation.

◆ **Richmond, A. and T. Malone. 1986.** Observed scarification rates and contract costs for the TTS-35 disc trencher in interior Alaska . Univ. of Alaska, Fairbanks. Agric. and Forestry Exp. Sta. Circular 53. 14 pp.

Author abstract. The regeneration of interior Alaska's commercial forest lands is mandated by Alaska's Forest Resources and Practices Act (1979). This act requires that regeneration be established adequate to ensure a sustained yield on forested lands from which the timber has been harvested. Post-logging regeneration efforts now are aimed at exposing mineral soil for the natural seeding of white spruce. Soil exposure has been accomplished by blade scarifying with a crawler tractor which provides large seed sites or by using a Bracke-type patch scarifier which produces small seed sites of about 2 ft2. Arlidge (1967) reports that larger seedbeds have greater regeneration success than smaller ones. Some researchers have found that the regeneration of the larger plots may be too successful, requiring weeding and precommercial thinning to bring stocking to satisfactory levels (Zasada and Grigal 1978). The Alaska Division of Forestry (DOF) has not been satisfied with the cost or effectiveness of either of these site-preparation practices.

◆ **Smith, G.K.M. 1988.** Site preparation in cold soils. Canadian Forest Industries. Sept. 1988: 32-34. Southam Business Publications, Don Mills, Ontario.

Compiler summary. This paper summarizes presentations from Canadian, Scandinavian, and US forestry researchers and practitioners. In summary, presenters agreed that root extension ceases and seedling growth slows down below a threshold temperature, typically about 5°C.

Specific effects differ among white and black spruce and jack pine. During spring planting operations, soil temperature can remain well below air temperature. Warm, loose soils provide drainage, promote root extension, and have high nutrient availability. Mounding site preparation works on certain sites because mounds capture and retain heat and allow root extension. Research on mounding is underway in Ontario and Michigan. Information is needed over a forest rotation to determine whether root systems adapt well to mounds and whether trees in mounds are susceptible to windthrow. Foresters and scientists agree that some type of site preparation to raise soil temperature is better than none. Skilled equipment operators are critical for successful mechanical scarification.

◆ **Wiensczyk, A., K. Swift, A. Morneault, N. Thiffault, K. Szuba, and F. W. Bell. 2011.** An overview of the efficacy of vegetation management alternatives for conifer regeneration in boreal forests. The Forestry Chronicle 87:175-200.

Author abstract. In this paper, we discuss the broad array of treatments that could be used to control competitive vegetation in conifer plantations in the boreal forests of Canada. We present vegetation management alternatives screened based on their treatment efficacy, which we defined as their ability to (a) control competitive vegetation and (b) not cause undue damage to conifer seedlings. The treatments reviewed range from pre-harvest (preventative) to post-plant release (reactive) treatments, and are organized into five categories: (i) silvicultural and harvest systems, (ii) physical treatments such as mechanical site preparation, cutting, girdling and mulching; (iii) thermal treatments such as prescribed fire and steaming; (iv) cultural treatments such as seedling culture, cover cropping, and grazing; and (v) chemical and biological spray treatments. We based our assessment of treatment efficacy on previous reviews, expert opinion, and published literature. We conclude on the need to further assess the effectiveness of forest vegetation management strategies in the context of multi-purpose plantations that consider ecological, social and silvicultural objectives.

◆ **Wurtz, T.L. 2000.** Interactions between white spruce and shrubby alders at three boreal forest sites in Alaska. PNW-GTR-481. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 29 p. http://www.fs.fed.us/pnw/pubs/gtr481.pdf

Author abstract. To document possible soil nitrogen mosaics before timber harvesting on three boreal forest sites in Alaska, maps of the distribution of understory green (Alnus crispa (Ait.) Pursh) and Sitka alder (A. sitchensis (Reg.) Rydb.) stems were made. Understory alders were regularly distributed throughout the northernmost site (Standard Creek) and very irregularly distributed at the southernmost site (Cooper Landing). No consistent relations existed between alder stem location and total soil nitrogen. In undisturbed forest, soils collected beneath alders tended to have more nitrogen than soils without alder, but after the sites were harvested, soil chemistry differed. To examine the interactions of alder and white spruce (Picea glauca (Moench) Voss) on secondary successional sites, mixed plantations of white spruce and alder were established after each site was harvested. Despite good survival, the planted alder grew poorly. No differences were found between nursery-grown alder seedlings and alder wildlings in either growth or survival. Although fifth-year survival and growth of white spruce were excellent on all sites, they were not related to either the preharvest distribution of naturally occurring alder or to alders planted in the mixed plantations. Locational information and site maps are provided for future evaluation of these plantations.

◆ **Youngblood, A., E. Cole, and M. Newton. 2011.** Survival and growth response of white spruce stock types to site preparation in Alaska. Canadian Journal of Forest Research **41**:793-809.

Author abstract. To identify suitable methods for reforestation, we evaluated the interacting effects of past disturbance, stock types, and site preparation treatments on white spruce (Picea glauca (Moench) Voss) seedling survival and growth across a range of sites in Alaska. Replicated experiments were established in five regions. At each site, two complete installations differed in time since disturbance: “new” units were harvested immediately before spring planting and “old” units were harvested at least 3 years before planting. We compared mechanical scarification before planting, broadcast herbicide application during the fall before planting, and no site preparation with 1-year-old container-grown seedlings from two sources, 2-year-old bare-root transplants from two sources, and 3-year-old bare-root transplants. Seedlings were followed for 11 years on most sites. Based on meta-analyses, seedling survival increased 10% with herbicide application and 15% with mechanical scarification compared with no site preparation. Scarification and herbicide application increased seedling height by about 28% and 35%, respectively, and increased seedling volume by about 86% and 195%, respectively, compared with no site preparation. Soil temperature did not differ among site preparation methods after the first 7 years. Results suggest that white spruce stands may be successfully restored through a combination of vegetation control and use of quality planting stock.

◆ **Zasada, J. and R. Norum. 1986.** Prescribed Burning White Spruce Slash in Interior Alaska. Northern Journal of Applied Forestry 3(1): 16-18.

Author abstract. Broadcast burning following harvesting on flood-plain sites in Alaska substantially decreased residual organic material and increased exposed mineral soil. Two forest types were studied: white spruce/alder/feathermoss and white spruce/alder/lingonberry/feather-moss. The latter site contained permafrost. Fuel was reduced 67% and 81%, respectively; organic horizon thickness was decreased 43% to 2.9 in (7.4 cm) and 55% to 2.5 in (6.4 cm), respectively; and mineral soil exposure was 13% and 8%, respectively. Burning created good conditions for planting on both types. In addition, mechanical site preparation to increase mineral soil exposure appears to be necessary to achieve adequate, well-distributed regeneration from seed.

Section 5
FIRE AND REGENERATION

SUMMARY

Teresa Hollingsworth, **USDA Forest Service, Pacific Northwest Research Station**

Fire is one of the most important landscape-level disturbances in Region III and plays a potentially increasingly important role in areas of Region II. Fire creates opportunities for rapid regeneration of existing plant species as well as potential hot spots for novel or non-native species.

Historically, fire has affected black spruce-dominated stands throughout regions II and III, at a frequency of approximately 70-200 years (Fastie et al. 2003), and white/Lutz spruce-dominated stands at a frequency of 400-600 years (Berg & Anderson 2006; Berg et. Al.2006). Over the last 6000 years, there has been relative stability in forest succession due to cold soils, low fire severity, and plant traits of the dominant species (Johnstone, et al. 2010a;Hollingsworth, et al. 2013) with a return to pre-fire species within 10 years of fire (Johnstone et al. 2004). However, unusual fire events can disrupt this stability through effects on fire severity.

Fire severity describes the effect of a fire on ecosystem properties and in particular mortality or consumption of vegetation. In northern forests, this is often measured by the amount of soil organic layer consumption because in general there is full canopy mortality (Johnstone and Kasischke 2005). Changes in climate are associated with increasingly large late-season fires (Kasischke et al. 2010) in Region III and early grassland fires in Region II (Morton 2013) both of which are correlated to an increase in fire severity.

Across both regions, fire severity is the single most important factor affecting regeneration post-fire. High severity fires expose mineral soil substrate which effects tree recruitment by seed (Green et al. 2007). Experimental and observational evidence on the germination of different seedbeds post-fire show that organic layer thickness is the single most important factor determining post-fire deciduous germination/recruitment (Johnstone & Chapin 2006b, Zasada et al. 1983), which in turn creates substrate for deciduous tree species to compete effectively (Johnstone et al. 2010b).

Additionally, site factors such as site moisture (which includes topography, presence of permafrost, and soil texture), pre-fire composition, and elevation are contributing factors to post-fire regeneration (Johnstone et al. 2008, Carter and Chapin 2000, Epting and Verbyla 2005, Bernhardt et al. 2010, Boucher 2003). It is important to note, however, that many of the above-listed factors interact with fire severity across the landscape, and therefore it is often hard to disentangle primary and secondary effects on post-fire regeneration.

There are other factors that affect species regeneration post-fire. Brown and Johnstone (2011) provide evidence that shortened fire return interval decreases seed availability, which in turn drastically reduces black spruce recruitment. White spruce post-fire regeneration is positively affected if there is a large mast year immediately following fire (Peters et al. 2005).

Model simulations suggest that the effects of climate warming on fire activity in Alaska's boreal forest may be partially but not completely mitigated by changes in fire severity that alter landscape patterns of forest composition and subsequent fire behavior (Johnstone et al. 2011)

There is strong evidence that logging does not emulate wildfire in terms of regeneration. There are differences in plant diversity (Rees and Juday 2002), stand structure (McRae et al. 2001), plant community composition (Haeussler and Bergeron 2004), and successional trajectory, and these differences in spatial signature can last up to 60 years (Lorente et al. 2013).

REFERENCES

◆ **Bella, E. M. 2012.** Tree regeneration rates in post-fire and post-beetle affected stands on the Kenai Peninsula. Unpublished report. Sept. 27, 2012. 38 pp.

Author abstract: A number of competing landscape cover models have been employed to predict future vegetation and fire regime change on the Kenai Peninsula. Model scenarios provide guidance for managing for change, but lack allowance for novel change or predictions of novel assemblages. Understanding tree regeneration dynamics in a post-beetle kill, warming climate may facilitate a transition to including novel assemblages and change in subsequent modeling efforts. In order to better understand natural tree regeneration rates to inform predictions, vegetation and cover data were collected on 45 plots in 9 sites with varying disturbance history. Sites were selected to represent reference conditions, recent (<20 years) fire-affected stands, and fire- and spruce bark beetle-affected stands. Data collection took place on five plots per site, including both bluejoint reedgrass presence and absence. A Pearson's correlation examined relationships between predictive site parameters and vegetation cover. Relationships between quantitative site, regeneration, and composition variables were analyzed through a nonmetric multidimensional scaling ordination. A multi-response permutation procedure was applied to overall site and various categorical disturbance parameters to determine plot independence. Fire severity affected ground cover and vegetation composition, which in turn impacted regeneration rates for spruce and birch. Data for quaking aspen and cottonwood regeneration was limited, so conclusions on regeneration rates were uncertain. Contributing factors to regeneration rates for birch and spruce also included bluejoint reedgrass presence and distance to seed source. Additional factors such as aspect and browse had no clear effect. An expanded study would include detailed fire severity and browse information, and target specific sites to include data for all tree species of interest. Additionally, sites could be expanded to include a greater spectrum of disturbance effects, including post-fire fuel reduction treatments, specific fire severity areas, beetle-only (no fire) areas, and targeted bluejoint reedgrass presence and absence locations.

◆ **Berg, E., 2004a.** Windy Point burn provides food through, and for moose, hares. Kenai Peninsula Clarion. Refuge Notebook. Aug. 13, 2004.

Compiler abstract. Column describes natural regeneration ten years after the 1994 Windy Point burn. Berg describes "doghair-thick stands of birch saplings" and abundant habitat for moose and hares. The Windy Point fire was a 2,800-acre severe, mineral soil exposing fire. The prior forest was mature upland black spruce and thick peat moss. The article references data from permanent plots established in the burn area.

◆ **Berg, E., 2004b.** Blown down trees reveal secrets of the forest – past and future. Kenai Peninsula Clarion. Refuge Notebook. Aug. 30, 2002.

Compiler abstract. Column describes evidence of fires and nurse logs in tree throw pits and mounds following the 1990s spruce beetle outbreak and subsequent logging on the Kenai Peninsula. Berg reports that previous generations of trees in the study area germinated either on exposed mineral soil following rare, intense fires, or on nurse logs. The intensity of the 1990s beetle outbreak left few pole-sized trees for advanced regeneration. Where logging occurred, most of the dead trees that could blow down and become nurse logs were removed. Some natural regeneration was observed in areas where logging equipment exposed mineral soil. Berg states that the best chance for regeneration in logged areas is replanting, and noted good survival of white spruce and lodgepole pine nursery seedlings.

◆ **Berg, E.E. and R.S. Anderson. 2006.** Fire history of white and Lutz spruce forests on the Kenai Peninsula, Alaska, over the last two millennia as determined from soil charcoal. For. Ecol. and Mgmt. 227: 275-283.

Author abstract. The presence of over 429,000 ha of forest with spruce (Picea spp.) recently killed by spruce beetles (Dendroctonus rufipennis) on the Kenai Peninsula has raised the specter of catastrophic wildfire. Dendrochronological evidence indicated that spruce beetle outbreaks occurred on average every 50 years in these forests. We used 121 radiocarbon-dated soil charcoal samples collected from throw mounds of recently blown over trees to reconstruct the regional fire history for the last ca. 2500 years and found no relation between fire activity and past spruce beetle outbreaks. Soil charcoal data suggest that upland forests of white (Picea glauca) and Lutz (Picea x lutzii) spruce have not on average burned for 600 years (time since-fire range 90 to _1500 years, at 22 sites) and that the mean fire interval was 400–600 years. It would thus appear that 10 or more spruce beetle outbreaks can occur for every cycle of fire in these forests. We caution, however, that a trend of warmer summers coupled with an increasing human population and associated sources of ignitions may create a greater fire risk in all fuel types than was present during the time period covered by our study. We suggest that forest management focus on creating fuel breaks between valued human infrastructure and all types of forest fuels, both green and dead.

◆ **Berg, E.E., R. S. Anderson, and A.D. De Volder. 2006a.** Fire history of spruce forests on the Kenai Peninsula, Alaska, on scales of decades to millennia, using fire scars, soil charcoal and lake sediments. http://depts.washington.edu/nwfire/publication/Berg_et_al_2006.pdf

Author introduction and results. The Kenai Peninsula has two distinct fire regimes: a high frequency regime in black spruce (*Picea mariana*) and a low frequency regime in white (*P. glauca*) and Lutz (*Picea* x *lutzii*) spruce. We examined these fire regimes on three different time scales, and estimated the mean fire return intervals and variances.

Black spruce: We used 189 fire scars to date 10 fires from 1708 to 1898. Fire return intervals ranged from 18 to 166 years, with a mean fire return interval (MFI) of 79 ± 35 (SD) years. (De Volder 1999)

White/Lutz spruce: We used 121 radiocarbon-dated soil charcoal samples to estimate an MFI of 515 ± 355 (SD) years over the last 2500 years, at 22 sites. Charcoal older than 2500 years was excluded from the MFI calculation because of concern about long-term disintegration of charcoal fragments and consumption of older charcoal by more recent fires. Times-since-fire ranged from 90 to 1518 years, with a mean of 605 ± 413 (SD) years. (Berg and Anderson 2006)

Sedimentary charcoal: Charcoal was measured at 1-cm intervals to provide a 13,000 year record of fire activity at Paradox Lake. Fire frequency was lowest during the initial shrub tundra period with an MFI of 138 ± 65 years beginning 13,000 years before present (BP), increased after the arrival of birch, *Salix*, and *Populus* at 10,700 years BP to an MFI of 77 ± 49 years, and decreased slightly to an MFI of 81 ± 41 years after the arrival of white spruce at 8500 years BP. After black spruce arrived at 4500 years BP, fire activity declined to the present MFI value of 130 ± 60 years, presumably reflecting the onset of a cooler and wetter climate. (Anderson et al. in press) The 130-year MFI estimated from sedimentary charcoal at Paradox Lake is considerably shorter than the 515-year MFI estimated from soil charcoal samples distributed over the central and southern Kenai Peninsula. This difference may be in part due to black spruce near Paradox Lake, but is more likely due to the fact that a lake can potentially accumulate charcoal from many fires distributed over a large area, whereas a soil charcoal sample represents a single fire at a single point on the landscape. Similar discrepancies have been reported in other studies comparing these two quite different methods (reviewed in Berg and Anderson 2006).

◆ **Bernhardt, E.L., T.N. Hollingsworth, and F.S. Chapin III. 2011.** Fire severity mediates climate-driven shifts in understorey community composition of black spruce stands of interior Alaska. Journal of Vegetation Science, 22: 32–44. doi: 10.1111/j.1654-1103.2010.01231.x

Author abstract. We compared plant community composition and environmental stand characteristics in 14 black spruce stands before and after multiple, naturally occurring wildfires. We used a combination of vegetation table sorting, univariate (ANOVA, paired *t*-tests), and multivariate (detrended correspondence analysis) statistics to determine the impact of fire severity and site moisture on community composition, dominant species and growth forms.

Severe wildfires caused a 50% reduction in number of plant species in our study sites. The largest species loss, and therefore the greatest change in species composition, occurred in severely burned sites. This was due mostly to loss of non-vascular species (mosses and lichens) and evergreen shrubs. New species recruited most abundantly to severely burned sites, contributing to high species turnover on these sites. As well as the strong effect of fire severity, pre-fire and post-fire mineral soil pH had an effect on post-fire vegetation patterns, suggesting a legacy effect of site acidity. In contrast, pre-fire site moisture, which was a strong determinant of pre-fire community composition, showed no relationship with post-fire community composition. Site moisture was altered by fire, due to changes in permafrost, and therefore post-fire site moisture overrode pre-fire site moisture as a strong correlate.

In the rapidly warming climate of interior Alaska, changes in fire severity had more effect on post-fire community composition than did environmental factors (moisture and pH) that govern landscape patterns of unburned vegetation. This suggests that climate change effects on future community composition of black spruce forests may be mediated more strongly by fire severity than by current landscape patterns. Hence, models that represent the effects of climate change on boreal forests could improve their accuracy by including dynamic responses to fire disturbance.

◆ **Boucher, T. V. 2003.** Vegetation response to prescribed fire in the Kenai Mountains, Alaska. PNW-RP-554. USDA Forest Service, Pacific Northwest Research Station, Anchorage, AK. 67 pp.

Between 1977 and 1997, 4000 ha were burned to promote regeneration of tree and shrub species used for browse by moose (*Alces alces*) in the Kenai Mountains. Species composition was documented along burned and unburned transects at 17 prescribed burn sites. Relationships among initial vegetation composition, physical site characteristics, browse species abundance, and competitive herbaceous vegetation were examined to determine controls on browse species regeneration after prescribed burning. Browse species abundance after burning was inversely related to *Calamagrostis canadensis* Michx. Beauv. (bluejoint reedgrass) abundance prior to burning. *Calamagrostis canadensis* abundance was related to specific landscape characteristics. Depositional slopes, such as fluvial valley bottoms and toe slopes, often featured soils with deep, loamy surface horizons. Sites with these characteristics generally showed large increases in *C. canadensis* cover after prescribed burning, even when *C. canadensis* was a low percentage (3 percent) of the canopy cover prior to burning. The most important preburn variables for predicting postburn browse species abundance were preburn *C. canadensis* cover and the type of surficial deposit. Site conditions that are favorable to *C. canadensis* may be problematic for successful regeneration of browse species, especially if browse species are not present in the initial composition.

◆ **Brown, C. D., and J. F. Johnstone. 2011.** Once burned, twice shy: Repeat fires reduce seed availability and alter substrate constraints on black spruce regeneration. Forest Ecology and Management 266:34–41.

Author Abstract. Widespread climate change is expected to lead to altered patterns of disturbance, thereby driving future ecosystem change. This interaction, which is often poorly recognized or understood, may be particularly important in the sub-arctic due to rapid climate change and frequent fire. Our objective was to investigate how an altered fire return interval can interrupt successional pathways in a serotinous boreal ecosystem. We conducted this research in black spruce (*Picea mariana* [Mill.] BSP.) forests on the northern margin of the species' distribution in Yukon Territory, Canada. We compared seed availability and seedling establishment of black spruce in stands of varying fire return interval using experimental manipulations within areas varying in their natural fire histories. Recruitment was drastically reduced following two closely timed fires, compared to stands burned under a typical fire return interval. However, recruitment was also limited in mature forest stands. On-site germination experiments demonstrated that black spruce recruitment was limited by seed availability after a short fire return interval, and by substrate quality in unburned stands. The vegetation of the boreal forest is thought to be highly resilient to climatic change, due in part to the adaptations that conifers have for post-fire regeneration. We show that shortened fire return intervals, through effects on seed availability, disrupt the normal sequence of post-fire recovery on seedbeds released by fire for colonisation. The results of this study provide strong empirical evidence that disturbance, although essential for stand renewal, may limit forest recovery or expansion when misaligned with reproductive cycles.

◆ **Cater, T.C. 1990.** Effect of vegetation competition on tree seedling establishment and growth in an upland, post-fire succession in Interior Alaska. Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 48 pp.

Author abstract. Location and density of naturally occurring Picea glauca seedlings were measured five years following fire to document natural establishment patterns. To estimate effects of competition on these patterns, P. glauca and Betula papyrifera were sown as seeds and transplanted as seedlings into distinct patches of vegetation where either Equisetum arvense, Calamagrostis canadensis, or Populus tremuloides was dominant (> 90% cover). Naturally occurring P. glauca seedlings preferentially established where E. arvense was dominant. Similarly, P. glauca and B. papyrifera establishment and growth were greater in E. arvense patches and clipped plots. Thus, colonizing species inhibit establishment of late successional species, with E. arvense being a weaker competitor than C. canadensis and P. tremuloides. Accumulated above and below-ground biomass were not good indicators of competitive ability. Environmental differences between patch types were positively correlated with the bioassay results: C. canadensis patches had thicker organic mats and cooler and wetter soils than other patch types.

◆ **Cater, T. C. and F. S. Chapin. 2000.** Differential effects of competition or microenvironment on boreal tree seedling establishment after fire. Ecology 81(4): 1086-1099.

Author abstract. We used a combination of surveys of natural vegetation and seed-sowing and seedling transplant experiments to determine the relative importance of competition and microenvironmental modification as mechanisms by which understory vegetation influences the establishment of tree seedlings in an Alaskan postfire boreal forest. Seedlings of white spruce (*Picea glauca*) and paper birch (*Betula papyrifera*) became established more frequently than expected in patches that were dominated by horsetail (*Equisetum arvense*), and less frequently than expected in patches of bluestem (*Calamagrostis canadensis*) and other vegetation. Similarly, birch and spruce, whether sown directly or transplanted as seedlings into horsetail-dominated patches generally showed greater survivorship, growth, and nitrogen accumulation (for birch only) than did those transplanted into bluestem or quaking aspen (*Populus tremuloides*) patches. Clipping experiments demonstrated that the presence of aboveground vegetation reduced survivorship (for birch only), growth (for both species), and nitrogen accumulation (for spruce only) in all patch types. Thus, the understory vegetation in all patch types competed with tree seedlings. However, patch × clipping interactions were either absent or could not explain the greater inhibition of seedling establishment by bluestem or aspen than by horsetail. The strong inhibitory effect of bluestem and aspen on the establishment of spruce and birch seedlings is best explained by the unfavorable temperature and moisture microenvironments in these patches, rather than by differential competition in patches of bluestem, horsetail, or aspen. Many asymmetrical species interactions that are thought to drive successional change may result more from the contrasting effects that species have on their environment than from resource competition among species.

◆ **Clautice, S.F. 1974.** Spruce and birch germination on different seedbeds and aspects after fire in interior Alaska . Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 94 pp.

Author abstract. Picea glauca (Moench) Voss., Picea mariana (Mill.) B.S.P., and Betula papyrifera March seed were sown on three post fire seedbeds on north and south aspects the first spring following a forest fire. Germination of seeds, survival of seedlings, and natural revegetation were observed during the succeeding summer. Intense burning provided the best seedbeds for tree seed and southern aspects supported the best seedling growth. All three species sown germinated on both aspects. Germination occurred almost wholly on mineral soil but a minor amount occurred on ash. Charred organic matter was too dry to support germination. Mineral soil on the north slope was cold and constantly wet; while that on south slopes was warmer, it was intermittently dry, and less germination occurred on these drier slopes. Picea glauca and Picea mariana germination patterns were very similar. Flooding, browsing, and overgrowth by Marchantia polymorphia L. were main causes of Picea mortality on the north slope. and Betula papyrifera seedlings did not grow after germination on the north slope. Picea glauca grew largest on the south slope. Picea mariana seedlings were of similar size on both aspects. On the south slope Betula papyrifera seedlings developed two or more leaves, in contrast to the stunted development of those on the north aspect. Picea mariana showed the highest overall survival on both aspects, Picea glauca was intermediate, and Betula papyrifera had the lowest survival. The most common naturally occurring revegetation originated from seed on the south slope and from vegetative means on the north slope.

◆ **Densmore, R. 1985.** Effect of microsite factors on establishment of white spruce seedlings following wildfire. Pp. 38-39 in: 37 in: Early results of the Rosie Creek Fire Research Project 1984. G.P. Juday and C.T. Dyrness, eds. Univ. of Alaska Fairbanks Agric. and For. Res. Exp. Sta. Misc. Publ. 85-2. 46 pp.

Compiler excerpt. White spruce stands destroyed by fire often do not regenerate to dense white spruce stands. Inadequate seed rain is often a problem, but the microsite conditions created directly and indirectly by the fire are also a factor. This study was intended to complement Zasada's work in the Sawmill road study area of the Rosie Creek Fire. The objectives were to identify microsite characteristics necessary for the establishment of white spruce seedlings following fire, and to evaluate the relative importance of the availability of suitable microsites in controlling he density of white spruce seedlings.

To date, I have found the most important microsite variables are soil characteristics and soil surface cover. Soil characteristics were largely determined by the depth to which the fire burned in the organic soil horizons. The most important soil surface characteristic is the presence of a layer of spruce needles. However, more data are required in order to evaluate the e3ffects of plant canopy and microrelief on white spruce seedling establishment.

Under most circumstances (especially limited seed rain), white spruce seedlings will establish only where fire has removed almost all the organic layer.

◆ **Epting, J. and D. Verbyla. 2005.** Landscape-level interactions of prefire vegetation, burn severity, and postfire vegetation over a 16-year period in interior Alaska. Canadian Journal of Forest Research, 2005, 35(6): 1367-1377, 10.1139/x05-060

Author abstract. Landsat imagery was used to study the relationship between a remotely sensed burn severity index and prefire vegetation and the postfire vegetation response related to burn severity within a 1986 burn in interior Alaska. Vegetation was classified prior to the fire and 16 years after the fire, and a chronosequence of remotely sensed vegetation index values was analyzed as a surrogate of vegetation recovery. Remotely sensed burn severity varied by vegetation class, with needle-leaf forest classes experiencing higher burn severity than broadleaf forest or broadleaf shrubland classes. Burn severity varied by cover within needle-leaf classes. Elevation also had an influence on burn severity, presumably as a result of there being less fuel above the treeline. Several large broadleaf areas at the fire perimeter appeared to act as fire breaks. A remotely sensed vegetation index peaked 8-14 years after the fire, and increase in the vegetation index was highest within the highest burn severity class. Self-replacement appeared to be the dominant successional pathway, with prefire needle-leaf forest classes mostly succeeding to needle-leaf woodland and with prefire broadleaf forest mostly succeeding to broadleaf shrubland. Because the remotely sensed indices were based on reflected solar radiation, they are likely indicative of surface properties, such as canopy destruction and surface charring, rather than subsurface properties, such as postfire depth of organic soil.

◆ **Fastie, C.L., A.H. Lloyd, and P. Doak. 2003.** Fire history and postfire forest development in an upland watershed of interior Alaska. J. Geophysicial Res. 108(D1): 8150, doi:10.1029/2001JD000570

Author abstract. We reconstructed the history of wildfire in the study area of the 1999 FROSTFIRE experimental fire in interior Alaska using information from fire-scarred trees, fire-killed trees, tree recruitment dates, tree radial growth increases, and aerial photographs. This combination of methods resulted in more temporal and spatial precision than would have been possible with any subset. Stand-destroying wildfires affected 93% of the FROSTFIRE watershed and 47% of the control watershed between 1896 and 1925. We found no evidence for severe fires earlier in the 19th century or later in the 20th century, suggesting a temporal cluster of fires. The ignition of some of these fires may be area. There is no evidence that any part of the study area has been burned by more than one severe fire in the past 200–250 years, suggesting fire frequencies lower than previously published estimates. Forests with prefire species composition developed within several decades following fire in birch forests and black spruce forests. South-facing birch forests show no evidence of succeeding to white spruce forests 200 years after fire.

◆ **Foote, M.J. 1995.** The role of fire in the boreal forest of interior Alaska, Proceedings of the 1994 Society of American Foresters Annual Convention, 18-22 September 1994, Anchorage, AK. Society of American Foresters, Bethesda, MD. p. 179-184.

Author abstract: Fire burns 3,000-1,000,000 acres annually. It is a natural part of the ecology of the boreal forest of interior Alaska. Fire alters the site, growing conditions on the site, site resiliency, and the habitat of users of the site. It promotes site productivity by recycling nutrients, warming soils, melting permafrost, and exposing patches of mineral soil which make excellent surfaces for germinating seeds. It maintains landscape diversity and promotes young, highly productive forests and high quality food material. However, the unprotected mineral soil may erode and stability of some of the ice-rich permafrost sites is destroyed, at least for a time.

◆ **Foote, M.J., and L.A. Viereck. 1985.** Burn severity: Its impact on the natural revegetation process following the Rosie Creek Fire. Pp. 26-29 in: Early results of the Rosie Creek Fire Research Project 1984. G.P. Juday and C.T. Dyrness, eds. Univ. of Alaska Fairbanks Agric. and For. Res. Exp. Sta. Misc. Publ. 85-2. 46 pp.

Compiler abstract. This paper documents responses post-fire for white spruce, black spruce, aspen, and birch sites. The authors predict future responses for each site, and include the following management implications.
1. Species currently on the site will orchestrate what happens in the near future. If this is acceptable to management, then there is not cause to change the natural course. If natural succession is not acceptable to management, it is important that various silvicultural treatments be considered as soon as possible.
2. When the various mechanisms a species uses to regenerate are known, managers can better predict how the species will react to various management activities. For example, if quaking aspen stems are pruned in winter above the snow line, they will probably regenerate to near pretreatment levels the following growing season, because the effective regenerating sites are still present a functional.
3. Managers should carefully consider cases where desired species are absent from a given site after a fire. The species may be absent because it is an Avoider species and the necessary site conditions do not yet exist' however, the abse3nt species may really be lost from the site unless the manager takes some remedial action to restore it.

◆ **Greene, D.F. and E.A. Johnson. 1999**. Modelling recruitment of *Populus tremuloides*, *Pinus banksiana*, and *Picea mariana* following fire in the mixedwood boreal forest. Canadian Journal of Forest Research, 1999, 29(4): 462-473, 10.1139/x98-211

Author abstract. We examined the relationship between the post-fire regeneration density of *Populus tremuloides* Michx., *Pinus banksiana* Lamb., and *Picea mariana* (Mill.) BSP and their pre-fire basal area density at the spatial scale of 70 m (the width of the stands studied) in four fires in central Saskatchewan and one in Quebec. For these three species with mechanisms for in situ reproduction, there were highly significant relationships between regeneration density and pre-fire basal area density (basal area per area). Given equal source basal area densities, *Populus tremuloides* has an advantage, relative to the other two species, in initial regeneration densities, but the advantage is not great because the asexual stems thin rapidly. The overriding conclusion is that, for these three species, there is little change in species composition following fire. Simple predictive equations performed reasonably well for *Pinus banksiana* and *Picea mariana*: $F_D = 806B_D^{0.95}$ and $F_D = 593B_D^{0.86}$, where F_D is regenerative stem density (no./m^2), and B_D is basal area density (m^2/m^2). For asexual reproduction by *Populus tremuloides*, the thinning begins immediately following fire, and the regeneration model was $F_D = 11\ 600B_D^{0.79}(t + 1)^{-1.64}$, where t is years since fire.

◆ **Greene, D.F., S.E. Macdonald, S. Cumming, and L. Swift. 2005.** Seedbed variation from the interior through the edge of a large wildfire in Alberta. Canadian Journal of Forest Research, 2005, 35(7): 1640-1647, 10.1139/x05-080

Author abstract. Despite the importance of seedbeds in the life histories of many plant species, there has been little study of the seedbeds created by wildfire in fire-prone vegetation types such as the boreal forest. Both within the interior and at the edge of a very large (>100 000 ha) 2001 wildfire in the mixedwood boreal region of Alberta, we examined the postfire duff depth and the percent coverage of seedbed types. Minimizing the effect of site and forest composition, we looked only at *Picea glauca* (Moench) Voss – *Populus tremuloides* Michx. sites burned during a single day of high fire intensity. Good seedbeds (thin humus and exposed mineral soil, with or without ash) averaged 35% coverage within the interior of the fire but varied enormously among stands. There was a weak but significant positive correlation between prefire percent white spruce basal area and percent mineral soil exposure; that is, there is some tendency for conifer stands to create the seedbeds best suited for their own germinants. Fire severity played a clear role in mineral soil exposure, which was greatest in areas with 100% canopy mortality. Mineral soil exposure was far less at the edges of the fire, averaging only 5% even in areas where all trees had been killed; the burn edge was characterized by superficial flaming combustion with no evidence of substantial duff removal via smoldering combustion. In short, the areas where white spruce seed will be most common after the fire, the edges, are where the worst seedbeds in the burn will be found. Regeneration microsites at fire edges appear to be better suited to regeneration of broadleaf species, via suckering; the persistence of white spruce in fire-prone landscapes continues to be difficult to explain.

◆ **Greene, D.F., S.E. Macdonald, S. Hauessler, S. Domenicano, J. Noel, K. Jayen, I. Charron, S. Gauthier, S. Hunt, E.T. Gielau, Y. Bergeron, and L. Swift. 2007.** The reduction of organic-layer depth by wildfire in the North American boreal forest and its effect on tree recruitment by seed. Canadian Journal of Forest Research, 2007, 37(6): 1012-1023, 10.1139/X06-245

Author abstract. We compared prefire and postfire organic-layer depths in boreal forest types (14 fires) across Canada, and examined tree recruitment as a function of depth. There was extensive within-stand variation in depth, much of it due to clustering of thinner organic layers around boles. There were no significant differences in postfire organic-layer depth among sites with different prefire forest species composition, but sites in the eastern boreal region had thicker postfire organic layers than those in the western boreal region. Mean organic-layer depth was much greater in intact stands than after fires; overall, fire reduced organic-layer depth by 60%, largely because of increases in the area of thin (<3 cm) organic layers (1% in intact stands vs. 40% in postfire stands). There was more variation in organic-layer depth within postfire than within prefire stands; notably, some areas in postfire stands were deeply combusted, while adjacent parts were only lightly combusted. We speculate that the diminished role of energy loss to latent heat around tree boles increased organic-layer consumption around tree boles. Seedlings were clustered around burned tree bases, where organic layers were thinner, and the dependence of a species on thin organic layers was an inverse function of seed size.

◆ **Haeussler, S. and Y. Bergeron. 2004.** Range of variability in boreal aspen plant communities after wildfire and clear-cutting. Canadian Journal of Forest Research, 2004, 34(2): 274-288, 10.1139/x03-274

Author abstract. Composition, structure, and diversity of vascular and nonvascular plant communities was compared 3 years after wildfire and clear-cutting in mesic trembling aspen (*Populus tremuloides* Michx.) forests of the southern Canadian boreal forest. We examined mean response to disturbance and variability around the mean across four to five spatial scales. Four 1997 wildfires were located near Timmins, Ontario, and ten 1996–1997 clearcuts were located adjacent to the wildfires. We randomly located plots within mesic, aspen-dominated stands selected to minimize predisturbance environmental differences. Correspondence analysis separated wildfire and clearcut samples based on community composition: wildfires had more aspen suckers, *Diervilla lonicera* Mill., and pioneering mosses; clearcuts had more under story tall shrubs, forbs, bryophytes, and lichens. Live tree basal area averaged 1.7 m^2/ha in wildfires and 1.8 m^2/ha in clearcuts ($p = 0.59$), and understory community structure (the horizontal and vertical distribution of live and dead plant biomass) was not markedly different. Clearcuts had higher species richness with greater variance than wildfires across all spatial scales tested, but differences in beta and structural diversity varied with spatial scale. Generally, clearcut–wildfire differences were more evident and wildfire variability greater at larger analytical scales, suggesting that plant biodiversity monitoring should emphasize cumulative effects across landscapes and regions.

◆ **Hollingsworth, T. N., J. F. Johnstone, E. Bernhardt, and F. S. Chapin III. 2013.** Fire severity filters regeneration traits to shape community assembly in Alaska's boreal forest. PLoS One 8:e56033. doi:10.1371/journal.pone.0056033.

Author abstract. Disturbance can both initiate and shape patterns of secondary succession by affecting processes of community assembly. Thus, understanding assembly rules is a key element of predicting ecological responses to changing disturbance regimes. We measured the composition and trait characteristics of plant communities early after widespread wildfires in Alaska to assess how variations in disturbance characteristics influenced the relative success of different plant regeneration strategies. We compared patterns of post-fire community composition and abundance of regeneration traits across a range of fire severities within a single pre-fire forest type– black spruce forests of Interior Alaska. Patterns of community composition, as captured by multivariate ordination with nonmetric multidimensional scaling, were primarily related to gradients in fire severity (biomass combustion and residual vegetation) and secondarily to gradients in soil pH and regional climate. This pattern was apparent in both the full dataset (n = 87 sites) and for a reduced subset of sites (n = 49) that minimized the correlation between site moisture and fire severity. Changes in community composition across the fire-severity gradient in Alaska were strongly correlated to variations in plant regeneration strategy and rooting depth.

The tight coupling of fire severity with regeneration traits and vegetation composition after fire supports the hypothesis that disturbance characteristics influence patterns of community assembly by affecting the relative success of different regeneration strategies. This study further demonstrated that variations in disturbance characteristics can dominate over environmental constraints in determining early patterns of community assembly. By affecting the success of regeneration traits, changes in fire regime directly shape the outcomes of community assembly, and thus may override the effects of slower environmental change on boreal forest composition.

◆ **Huggard, D.J., B.E. Grover, E. Dzus, M. Smith, J. Schieck. 2015.** Effectiveness monitoring for biodiversity: comparing 15 year old structural retention harvest areas to fires in boreal aspen. *Canadian Journal of Forest Research*, 2015, 45(2): 153-161, 10.1139/cjfr-2014-0091

Author abstract. Convergence of species composition in regenerating harvested areas and naturally disturbed forest is a critical component of forest management modeled after natural disturbances. We assessed convergence of birds, plants, and habitat structures in aspen (*Populus tremuloides*) stands harvested with structural retention by Alberta-Pacific Forest Industries Inc. (Al-Pac) 15 years ago with similar aged fire area, and examined a chronosequence of younger and older burned aspen stands from Alberta Biodiversity Monitoring Institute (ABMI) sites. Most habitat structures and many bird and plant species in the 15 year harvest areas were at levels similar to 20–40 year or >40 year fire areas. Snags, moss, and lichen cover, and a few groups of species were at lower levels in the harvest areas than comparable aged fire areas or older stands. Agglomerative clustering showed the plant community to be most similar to >40 year burned stands, with the bird community intermediate between >20 year and <20 year fire areas. A novel likelihood-based analysis of species estimated the 15 year harvest areas to have a community similar to forest sites with 36.8% human footprint, indicating substantial recovery of the harvest areas. Harvesting aspen stands with structural retention appears to be effective at allowing most biodiversity components to recover rapidly.

◆ **Hunter, M.L., Jr. 1993.** Natural fire regimes as spatial models for managing boreal forests. Biological Conservation 65:115-120. [L]

Author abstract. Because organisms have adapted to the natural disturbance regimes of forest ecosystems such as fires and windfalls, conservationists often suggest that timber harvesting systems be designed to imitate natural disturbance regimes. Using the crown fires that shape true boreal forest ecosystems as spatial models for harvesting would require very large clearcuts, in two studies, mean fire size was 12,710 ha (in Labrador) and 7764 ha (in Quebec). Most conservationists would be reluctant to advocate such large clearcuts and it is not easy to justify them from the perspectives of various ethical systems. A solution is proposed in which moderate-sized clearcuts would be clustered into portions of land areas bounded by water-bodies. These water-bounded areas have an average size of 770 ha in Labrador and 322 ha in Quebec.

◆ **Johnstone, J.F. 2008.** A key for predicting postfire successional trajectories in black spruce stands of interior Alaska. U.S. Dept. of Agriculture, Forest Service, Pacific Northwest Research Station. GTR-PNW-767. 37 pp.

Author abstract: Black spruce (*Picea mariana* (Mill) B.S.P) is the dominant forest cover type in interior Alaska and is prone to frequent, stand-replacing wildfires. Through impacts on tree recruitment, the degree of fire consumption of soil organic layers can act as an important determinant of whether black spruce forests regenerate to a forest composition similar to the prefire forest, or to a new forest composition dominated by deciduous hardwoods. Here we present a simple, rule-based framework for predicting fire-initiated changes in forest cover within Alaska's black spruce forests. Four components are presented: (1) a key to classifying potential site moisture, (2) a summary of conditions that favor black spruce self-replacement, (3) a key to predicting postfire forest recovery in recently burned stands, and (4) an appendix of photos to be used as a visual reference tool. This report should be useful to managers in designing fire management actions and predicting the effects of recent and future fires on postfire forest cover in black spruce forests of interior Alaska.

◆ **Johnstone, J. F. 2006.** Response of boreal plant communities to variations in previous fire-free interval. International Journal of Wildland Fire 15:497–508.

Author abstract. The present study used overlapping burn scars from natural wildfires to examine the effects of changes in the fire-free interval on early successional plant communities in boreal forests of central Yukon Territory, Canada. Data on plant community composition and residual organic material were collected in the first decade of post-fire regeneration in two study areas with recent fire overlap. Sites with a shorter fire-free interval had reduced loads of deadwood and shallower organic layers after the most recent fire. Multivariate analysis of species cover indicated that sites in and out of the burn overlap zones also supported distinct plant communities. Differences in the plant communities were associated with a greater abundance of woody deciduous species, such as Populus tremuloides, Salix spp., and Shepherdia canadensis, at sites that had recently re-burned. Sites that burned after a longer interval had higher moss cover and greater abundance of Picea mariana, Calamagrostis canadensis, and Ribes glandulosum in one study area, and Epilobium angustifolium in the second area. Ordinations of species cover indicated that plant community patterns were most strongly associated with gradients related to fire history and topography. In general, shorter fire-free intervals reduced pools of residual plant material and favored dominance of resprouting, woody deciduous species.

◆ **Johnstone, J. 2005.** Effects of aspen (*Populus tremuloides*) sucker removal on postfire conifer regeneration in central Alaska. CJFR 2005, 35(2): 483-486, 10.1139/x04-171.

Author abstract. This experiment tests the effects of early canopy development by asexually regenerating aspen (*Populus tremuloides* Michx.) on conifer recruitment after fire in central Alaska. The establishment and growth of three conifer species were observed in response to aboveground removal of aspen suckers for three seasons after burning by wildfire. Of the three species, *Pinus contorta* Dougl. ex Loud. had the most widespread seed germination and showed the strongest negative response to the presence of the aspen canopy. *Picea mariana* (Mill.) BSP and *Picea glauca* (Moench) Voss had low germination and weak or neutral responses to aspen removal. Seedlings of all species accumulated more biomass in the removal treatment. Results from the experiment suggest that competition by aspen early after disturbance can significantly reduce conifer recruitment and growth, an effect that may reinforce the long-term dominance of aspen in asexually regenerating stands.

◆ **Johnstone, J.F. 2003.** Fire and successional trajectories in boreal forest: implications for response to a changing climate. Ph.D. thesis, University of Alaska Fairbanks, Fairbanks, Alaska.

Author summary. Because of the key role played by fire in structuring boreal forest ecosystems, interactions between vegetation and fire regime may be an important and dynamic control of forest response to climate change. This research uses a series of field observations and experiments in boreal forests to examine the nature of several potential fire and vegetation interactions, and how such interactions may influence forest response to climate change. Long-term observations of post-fire succession provide information on the timing of tree establishment and the effects of early establishment on subsequent successional trajectories. The role of competitive interactions in driving patterns of early establishment was tested with experimental manipulations of aspen (Populus tremuloides) cover after fire. This research demonstrated that competition by aspen re-sprouts may reduce the success of conifer establishment and favor long-term dominance by deciduous trees. The effects of fire severity on successional trajectories were tested in a series of field experiments that contrasted patterns of seedling establishment across differences in depth of the post-fire organic layer. All species in the experiment responded negatively to decreased fire severity, but deciduous trees were more sensitive in their response than conifers. Thus, variations in bum severity are likely to mediate deciduous establishment in organic-rich stands. Observations of natural tree regeneration in stands that burned at different ages also indicate that a decrease in fire interval can influence the relative abundance of deciduous and coniferous species by reducing conifer establishment. Over longer time scales, changes in biota caused by species migration may influence fire and vegetation interactions. Observations of post-fire regeneration at the current distribution limits of lodgepole pine (Pinus contorta) indicate that continued range expansion of pine could initiate rapid shifts in dominance from spruce to pine within a single fire cycle. Together, these results provide insight into the dynamic feedbacks between fire and vegetation that can lead to high levels of system resilience, while also promoting rapid responses when threshold conditions are crossed. A more complete understanding of these interactions will improve our ability to manage and predict boreal ecosystem responses to a changing climate.

◆ **Johnstone, J. F., and F. S. Chapin III. 2006a.** Fire interval effects on successional trajectory in boreal forests of Northwest Canada. Ecosystems 9:268–277.

Author abstract. Although succession may follow multiple pathways in a given environment, the causes of such variation are often elusive. This paper describes how changes in fire interval mediate successional trajectory in conifer-dominated boreal forests of northwestern Canada. Tree densities were measured 5 and 19 years after fire in permanent plots and related to pre-fire vegetation, site and fire characteristics. In stands that were greater than 75 years of age when they burned, recruitment density of conifers was significantly correlated with pre-fire species basal area, supporting the expectation of stand self-replacement as the most common successional pathway in these forests. In contrast, stands that were under 25 years of age at the time of burning had significantly reduced conifer recruitment, but showed no change in recruitment of trembling aspen (Populus tremuloides). As a result, young-burned stands had a much higher probability of regenerating to deciduous dominance than mature-burned stands, despite the dominance of both groups by spruce (Picea mariana and Picea glauca) and pine (Pinus contorta) before the fire. Once initiated, deciduous-dominated stands may be maintained across subsequent fire cycles through mechanisms such as low on-site availability of conifer seed, competition with the aspen canopy, and rapid asexual regeneration of aspen after fire. We suggest that climate-related increases in fire frequency could trigger more frequent shifts from conifer to deciduous-dominated successional trajectories in the future, with consequent effects on multiple ecosystem processes.

◆ **Johnstone, J. F., and F. S. Chapin III. 2006b.** Effects of soil burn severity on post-fire tree recruitment in boreal forests. Ecosystems 9:14–31.

Author abstract. Fire, which is the dominant disturbance in the boreal forest, creates substantial heterogeneity in soil burn severity at patch and landscape scales. We present results from five field experiments in Yukon Territory, Canada, and Alaska, USA that document the effects of soil burn severity on the germination and establishment of four common boreal trees: Picea glauca, Picea mariana, Pinus contorta subsp. latifolia, and Populus tremuloides. Burn severity had strong positive effects on seed germination and net seedling establishment after 3 years. Growth of transplanted seedlings was also significantly higher on severely burned soils. Our data and a synthesis of the literature indicated a consistent, steep decline in conifer establishment on organic soils at depths greater than 2.5 cm. A metaanalysis of seedling responses found no difference in the magnitude of severity effects on germination versus net establishment. There were, however, significant differences in establishment but not germination responses among deciduous trees, spruce, and pine, suggesting that small-seeded species experience greater mortality on lightly burned, organic soils than large-seeded species. Together, our analyses indicate that variations in burn severity can influence multiple aspects of forest stand structure, by affecting the density and composition of tree seedlings that establish after fire. These effects are predicted to be most important in moderately-drained forest stands, where a high potential variability in soil burn severity is coupled with strong severity effects on tree recruitment.

◆ **Johnstone, J.F., T.N. Hollingsworth, and F.S. Chapin III 2008.** A key for predicting postfire successional trajectories in black spruce stands of interior Alaska. U.S. Dept. of Agriculture, Forest Service, Pacific Northwest Research Station. GTR-PNW-767. 37 pp.

Author abstract. Black spruce (*Picea mariana* (Mill) B.S.P) is the dominant forest cover type in interior Alaska and is prone to frequent, stand-replacing wildfires. Through impacts on tree recruitment, the degree of fire consumption of soil organic layers can act as an important determinant of whether black spruce forests regenerate to a forest composition similar to the prefire forest, or to a new forest composition dominated by deciduous hardwoods. Here we present a simple, rule-based framework for predicting fire-initiated changes in forest cover within Alaska's black spruce forests. Four components are presented: (1) a key to classifying potential site moisture, (2) a summary of conditions that favor black spruce self-replacement, (3) a key to predicting postfire forest recovery in recently burned stands, and (4) an appendix of photos to be used as a visual reference tool. This report should be useful to managers in designing fire management actions and predicting the effects of recent and future fires on postfire forest cover in black spruce forests of interior Alaska.

◆ **Johnstone, J. F., T. N. Hollingsworth, F. S. Chapin III, and M. C. Mack. 2010b.** Changes in fire regime break the legacy lock on successional trajectories in Alaskan boreal forest. Global Change Biology 16:1281–1295.

Author abstract. Predicting plant community responses to changing environmental conditions is a key element of forecasting and mitigating the effects of global change. Disturbance can play an important role in these dynamics, by initiating cycles of secondary succession and generating opportunities for communities of long-lived organisms to reorganize in alternative configurations. This study used landscape-scale variations in environmental conditions, stand structure, and disturbance from an extreme fire year in Alaska to examine how these factors affected successional trajectories in boreal forests dominated by black spruce. Because fire intervals in interior Alaska are typically too short to allow relay succession, the initial cohorts of seedlings that recruit after fire largely determine future canopy composition. Consequently, in a dynamically stable landscape, postfire tree seedling composition should resemble that of the prefire forest stands, with little net change in tree composition after fire. Seedling recruitment data from 90 burned stands indicated that postfire establishment of black spruce was strongly linked to environmental conditions and was highest at sites that were moist and had high densities of prefire spruce. Although deciduous broadleaf trees were absent from most prefire stands, deciduous trees recruited from seed at many sites and were most abundant at sites where the fires burned severely, consuming much of the surface organic layer. Comparison of pre- and postfire tree composition in the burned stands indicated that the expected trajectory of black spruce self-replacement was typical only at moist sites that burned with low fire severity. At severely burned sites, deciduous trees dominated the postfire tree seedling community, suggesting these sites will follow alternative, deciduous-dominated trajectories of succession. Increases in the severity of boreal fires with climate warming may catalyze shifts to an increasingly deciduous-dominated landscape, substantially altering landscape dynamics and ecosystem services in this part of the boreal forest.

◆ **Johnstone, J., L. Boby, E. Tissier, M. Mack, D. Verbyla, X. Walker. 2009.** Postfire seed rain of black spruce, a semiserotinous conifer, in forests of interior Alaska. CJFR 39(8): 1575-1588, 10.1139/X09-068**.**

Author abstract. The availability of viable seed can act as an important constraint on plant regeneration following disturbance. This study presents data on seed quantity and quality for black spruce (Picea mariana (Mill.) B.S.P.), a semiserotinous conifer that dominates large areas of North American boreal forest. We sampled seed rain and viability for 2 years after fire (2005–2007) in 39 sites across interior Alaska that burned in 2004. All sites were dominated by black spruce before they burned. Structural equation modeling was used to assess the relative importance of prefire spruce abundance, topography effects, canopy fire severity, and distance to unburned stands in explaining variations in black spruce seed rain. Prefire basal area of spruce that remained standing after fire was a significant predictor of total seed rain, but seed viability was more strongly related to site elevation, canopy fire severity, and distances to unburned stands. Although positive relations between tree basal area and the size of the aerial seed bank may place a first constraint on seed availability, accurate prediction of postfire viable seed rain for serotinous conifers also requires consideration of the effects of abiotic stress and canopy fire severity on seed viability.

◆ **Johnstone, J.F., F.S. Chapin III, J. Foote, S. Kemmett, K. Price, and L. Viereck. 2004.** Decadal observations of tree regeneration following fire in boreal forests. Can. J. For. Res. 34:267-273.

Author abstract: This paper presents data on early postfire tree regeneration. The data were obtained from repeated observations of recently burned forest stands along the Yukon – British Columbia border and in interior Alaska. Postfire measurements of tree density were made periodically for 20–30 years, providing direct observations of early establishment patterns in boreal forest. Recruitment rates of the dominant tree species in both study areas were highest in the first 5 years after fire, and additional net establishment was not observed after 10 years. The postfire population of spruce (*Picea mariana* (Mill.) BSP and *Picea glauca* (Moench) Voss s.l.) remained constant after the first decade in the two study areas. Populations of aspen (*Populus tremuloides* Michx.) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.var. *latifolia* Engelm.) both declined after 10 years in mixed-species stands along the Yukon – British Columbia border. Mortality rates of aspen and pine were positively correlated with their initial densities, indicating that thinning occurred as a density-dependent process. At all sites, measurements of stand density and composition made early were highly correlated with those made late in the monitoring period, indicating that patterns of stand structure initiated within a few years after fire are maintained through subsequent decades of stand development.

◆ **Johnstone, J.F., F.S Chapin, T.N. Hollingsworth, M.C. Mack, V. Romanovsky, M. Turetsky. 2010a.** Fire, climate change, and forest resilience in interior Alaska. CJFR 40(7): 1302-1312, 10.1139/X10-061

Author abstract. In the boreal forests of interior Alaska, feedbacks that link forest soils, fire characteristics, and plant traits have supported stable cycles of forest succession for the past 6000 years. This high resilience of forest stands to fire disturbance is supported by two interrelated feedback cycles: (*i*) interactions among disturbance regime and plant–soil–microbial feedbacks that regulate soil organic layer thickness and the cycling of energy and materials, and (*ii*) interactions among soil conditions, plant regeneration traits, and plant effects on the environment that maintain stable cycles of forest community composition. Unusual fire events can disrupt these cycles and trigger a regime shift of forest stands from one stability domain to another (e.g., from conifer to deciduous forest dominance). This may lead to abrupt shifts in forest cover in response to changing climate and fire regime, particularly at sites with intermediate levels of moisture availability where stand-scale feedback cycles are only weakly constrained by environmental conditions. However, the loss of resilience in individual stands may foster resilience at the landscape scale, if changes in the landscape configuration of forest cover types feedback to stabilize regional patterns of fire behavior and climate conditions.

◆ **Johnstone, J.F. and E.S. Kasischke, 2005**. Stand-level effects of soil burn severity on postfire regeneration in a recently burned black spruce forest. Canadian Journal of Forest Research 35, 2151-2163.

Author abstract. This study tested whether variations in soil burn severity (soil organic layer consumption) influenced patterns of early postfire plant regeneration in a black spruce (*Picea mariana (Mill.) BSP*) forest in interior Alaska. Variations in burn severity were related to measurements of postfire tree seedling establishment and cover of plant growth forms observed 7–8 years after fire. Black spruce and trembling aspen (*Populus tremuloides Michx.*) showed significant and opposite responses of seedling density to changes in soil burn severity. Positive correlations between burn severity and aspen density and individual seedling biomass led to an increase of over three orders of magnitude in aspen standing biomass (aboveground, g/m2) from the least to most severely burned sites. Variations in aspen productivity and consequent effects on litter production and seedbed quality possibly explain the observed negative response of black spruce density to increasing burn severity. Variations in the cover of several plant growth forms were also strongly correlated with patterns of soil burn severity. Regenerating plant communities in low-severity sites had a greater cover of evergreen shrubs and graminoids, while high-severity sites had increased cover of aspen and acrocarpous mosses. Observations of regeneration patterns in the burn are largely consistent with experimental studies of severity effects and suggest that variations in soil burn severity can have a strong influence on landscape patterns of postfire forest recovery. In this case, increases in burn severity have shifted successional trajectories away from simple conifer self-replacement towards a trajectory of mixed conifer and deciduous dominance.

◆ **Johnstone, J.F., Rupp, T.S., Olson, M., and Verbyla, D. 2011**. Modeling impacts of fire severity on successional trajectories and future fire behavior in Alaskan boreal forests. Landsc. Ecol. 26, 487-500.

Author abstract. Much of the boreal forest in western North America and Alaska experiences frequent, stand-replacing wildfires. Secondary succession after fire initiates most forest stands and variations in fire characteristics can have strong effects on pathways of succession. Variations in surface fire severity that influence whether regenerating forests are dominated by coniferous or deciduous species can feedback to influence future fire behavior because of differences in forest flammability. We used a landscape model of fire and forest dynamics to explore the effects of different scenarios of surface fire severity on subsequent forest succession and potential fire activity in interior Alaska. Model simulations indicated that high levels of surface fire severity leading to a prolonged phase of deciduous forest dominance caused a reduction in landscape flammability and fewer large fire events. Under low surface fire severity, larger patches of contiguous conifer forest promoted fire spread and resulted in landscapes with shorter fire return intervals compared to scenarios of high surface severity. Nevertheless, these negative feedbacks between fire severity, deciduous forest cover, and landscape flammability were unable to fully compensate for greater fire activity under scenarios of severe climate warming. Model simulations suggest that the effects of climate warming on fire activity in Alaska's boreal forests may be partially but not completely mitigated by changes in fire severity that alter landscape patterns of forest composition and subsequent fire behavior.

◆ **Juday, G.P. 2005.** Reserve West Seedling Establishment and Growth after Fire 1988 - 2009, Bonanza Creek LTER - University of Alaska Fairbanks. BNZ:91**.**
http://www.lter.uaf.edu/data_detail.cfm?datafile_pkey=91

Author abstract. In 1983 and 8,600 acre human-caused wildfire, the Rosie Creek Fire, burned through about 1/3 of the Bonanza Creek Experimental Forest unit of the Bonanza Creek LTER in central Alaska. The stand that burned was a productive white spruce dominated stand about 200 years old. This study of tree regeneration was initiated in 1989 in a 100m by 100m reference hectare at the perimeter of the Rosie Creek Burn, located between 100m and 200m from the surviving stand edge. The Reserve West reference hectare was reserved from salvage logging and artificial reforestation. All regenerating white spruce trees in the hectare have been mapped and seedling survival and height elongation have been measured annually since 1989 (1988 and 1987 tree heights were back calculated from internodes). Seedlings are tracked by a subdivision of the hectare into 100 cells of 10m by 10m. The total number of trees that have been tracked in the database is 2,527. This is one of the largest and longest complete data series examining forest regeneration in the boreal region.

◆ **Juday, G.P., R.V. Densmore, and J.C. Zasada. 2013**. White Spruce Regeneration Silviculture Techniques 25 years after Wildfire: the Rosie Creek Fire Tree Regeneration Installation. In: Camp, A.E.; Irland, L.C.; Carroll, C.J.W. (eds.) Long-term Silvicultural & Ecological Studies: Results for Science and Management, Volume 2.

Author abstract. This article describes the origin and potential future of a large assisted regeneration installation for white spruce, the largest experimental silvicultural installation known to the authors in boreal Alaska.

◆ **Juday, G. P. and C. T. Dyrness, editors. 1985.** Early results of the Rosie Creek Fire Research Project., University of Alaska, Agricultural and Forestry Experiment Station, Fairbanks, Alaska, USA. Miscellaneous Publication 85-2

Author abstract. The purpose of this report is to provide a first account of the projects supported or about to be launched at the time of a December 4, 1984 meeting titled, 'Rosie Creek Fire Research Project, 1984 Research Progress Meeting.' None of the projects had been completed at the time of this meeting, which was only 17 months after the fire; all the results reported in this volume are preliminary. However, several of the research topics deal with immediate post-fire effects, so that a substantial base of information is available in those studies. In the case of projects that had not been launched at the time of the meeting, the authors were asked to report only their research rationale and approach. This volume is intended to provide information, which may be of immediate use, to practicing foresters and other resource management professionals in interior Alaska. It also serves as an accounting to the interested public as well as administrators and legislators who have supported the work. The meeting and information exchange reported here also serve to inform a diverse set of researchers of the full range of investigations underway, and alert them or others scientists to the opportunities for integration of research, other types of collaboration, and/or synthesis of results.

◆ **Kasischke, E.S., D.L. Verbyla, T.S. Rupp, A.D. McGuire, K.A. Murphy, R. Jandt, J.L. Barnes, E.E. Hoy, P.A. Duffy, M. Calef, and M.R. Turetsky. 2010.** Alaska's changing fire regime — implications for the vulnerability of its boreal forests. Canadian Journal of Forest Research, 2010, 40(7): 1313-1324, 10.1139/X10-098

Author abstract. A synthesis was carried out to examine Alaska's boreal forest fire regime. During the 2000s, an average of 767 000 ha/year^{-1} burned, 50% higher than in any previous decade since the 1940s. Over the past 60 years, there was a decrease in the number of lightning-ignited fires, an increase in extreme lightning-ignited fire events, an increase in human-ignited fires, and a decrease in the number of extreme human-ignited fire events. The fraction of area burned from human-ignited fires fell from 26% for the 1950s and 1960s to 5% for the 1990s and 2000s, a result from the change in fire policy that gave the highest suppression priorities to fire events that occurred near human settlements. The amount of area burned during late-season fires increased over the past two decades. Deeper burning of surface organic layers in black spruce (Picea mariana (Mill.) BSP) forests occurred during late-growing-season fires and on more well-drained sites. These trends all point to black spruce forests becoming increasingly vulnerable to the combined changes of key characteristics of Alaska's fire regime, except on poorly drained sites, which are resistant to deep burning. The implications of these fire regime changes to the vulnerability and resilience of Alaska's boreal forests and land and fire management are discussed.

◆ **Kishchuk, B.E., E. Thiffault, M. Lorente, S. Quideau, T. Keddy, and D. Sidders. 2015.** Decadal soil and stand response to fire, harvest, and salvage-logging disturbances in the western boreal mixedwood forest of Alberta, Canada. Can. J. For. Res. 45: 141–152 (2015) dx.doi.org/10.1139/cjfr-2014-0148

Author abstract: Empirical knowledge of long-term ecosystem response to single and compound disturbances is essential for predicting disturbance effects and identifying management practices to maintain productive capacity of managed and restored landscapes. We report on soil, foliar nutrition, and regeneration growth response to wildfire, clearcut harvesting, and postfire salvage logging, as well as undisturbed control stands within the first year following disturbance and 10–11 years after disturbance in trembling aspen – white spruce mixedwood forests near Lesser Slave Lake, north-central Alberta, Canada. The compound disturbance of salvage logging resulted in greater long-term impacts on forest floor properties than either wildfire or harvesting alone. Changes in forest floor properties such as carbon and nitrogen pools and cation exchange capacity under salvage logging have persisted for 10 years and exhibit a different recovery trajectory than fire or harvesting. Forest floor properties under harvesting, including depth, carbon content, pH, extractable ammonium, and extractable sulphur, were not different from the control condition 10 years after harvest. Effects on soil and foliar nutrition were not reflected in productivity (height and diameter) of regenerating vegetation. Our results show differences between short- and long-term responses to disturbance, among single natural and anthropogenic disturbances, and among single and compound disturbances.

◆ **Lorente, L., W.F.J. Parsons, E.J.B. McIntire, and A.D. Munson. 2013.** Wildfire and forest harvest disturbances in the boreal forest leave different long-lasting spatial signatures. Plant Soil, 364, 1-2, pp. 39-54. Springer.

Author abstract. Natural disturbances leave long-term legacies that vary among landscapes and ecosystem types, and which become integral parts of successional processes at a given location. As humans change land use, not only are immediate post-disturbance patterns altered, but the processes of recovery themselves are likely altered by the disturbance. We assessed whether short-term effects on soils and vegetation that distinguish wildfire from forest harvest persist over 60 years after disturbance in boreal black spruce forests, or post-disturbance processes of recovery promote convergence of the two disturbance types. Using semi-variograms and Principal Coordinates of Neighbour Matrices, we formulated precise, a priori spatial hypotheses to discriminate spatial signatures following wildfire and forest harvest both over the short-(16-18 years) and long-term (62-98 years). Both over the short- and long-term, wildfire generated a wide spectrum of responses in soil and vegetation properties at different spatial scales while logging produced simpler patterns corresponding to the regular linear pattern of harvest trails and to pre-disturbance ericaceous shrub patches that persist between trails. Disturbance by harvest simplified spatial patterns associated with soil and vegetation properties compared to patterns associated with natural disturbance by fire. The observed differences in these patterns between disturbance types persist for over 60 years. Ecological management strategies inspired by natural disturbances should aim to increase the complexity of patterns associated with harvest interventions.

◆ **McRae, D.J., L.C. Duchesne, B. Freedman, T.J. Lynham, and S. Woodley. 2001.** Comparisons between wildfire and forest harvesting and their implications in forest management. Environmental Reviews, 2001, 9(4): 223-260, 10.1139/a01-010

Author abstract. Emulation silviculture is the use of silvicultural techniques that try to imitate natural disturbances such as wildfire. Emulation silviculture is becoming increasingly popular in Canada because it may help circumvent the political and environmental difficulties associated with intensive forest harvesting practices. In this review we summarize empirical evidence that illustrates disparities between forest harvesting and wildfire. As a rule, harvesting and wildfire affect biodiversity in different ways, which vary a great deal among ecosystem types, harvesting practices, and scale of disturbance. The scales of disturbance are different in that patch sizes created by logging are a small subset of the range of those of wildfire. In particular, typical forestry does not result in the large numbers of small disturbances and the small number of extremely large disturbances created by wildfires. Moreover, the frequency of timber harvesting is generally different from typical fire return intervals. The latter varies widely, with stand-replacing fires occurring in the range of 20 to 500 years in Canada. In contrast, harvest frequencies are dictated primarily by the rotational age at merchantable size, which typically ranges from 40 to 100 years. Forest harvesting does not maintain the natural stand-age distributions associated with wildfire in many regions, especially in the oldest age classes. The occurrence of fire on the landscape is largely a function of stand age and flammability, slope, aspect, valley orientation, and the location of a timely ignition event. These factors result in a complex mosaic of stand types and ages on the landscape. Timber harvesting does not generally emulate these ecological influences. The shape of cut blocks does not follow the general ellipse pattern of wind driven fires, nor do harvested stands have the ragged edges and unburned patches typically found in stand-replacing fires. Wildfire also leaves large numbers of snags and abundant coarse woody debris, while some types of harvesting typically leave few standing trees

and not much large debris. Successional pathways following logging and fire often differ. Harvesting tends to favor angiosperm trees and results in less dominance by conifers. Also, understory species richness and cover do not always recover to the pre-harvest condition during the rotation periods used in typical logging, especially in eastern Canada and in old-growth forests. As well, animal species that depend on conifers or old-growth forests are affected negatively by forest harvesting in ways that may not occur after wildfire. The road networks developed for timber extraction cause erosion, reduce the areas available for reforestation, fragment the landscape for some species and ecological functions, and allow easier access by humans, whereas there is no such equivalency in a fire-disturbed forest. *Key words*: silviculture, forest management, clearcutting, forest conservation, wildfire, biodiversity.

◆ **Morton, J. 2013.** Refuge Notebook: Fire (and moose) by the numbers. US Fish and Wildlife Service Kenai National Wildlife Refuge. Peninsula Clarion April 18, 2013.

Compiler abstract. This article reviews mean fire return intervals for forest types on the Kenai Peninsula and discusses changing fire patterns and vegetation responses. Large fires on the peninsula are shifting from summer lightning-caused fires in spruce forests to springtime human-caused fires in grasslands. The author notes that roughly 50% of every acre burned in spruce on the Kenai National Wildlife Refuge historically converted to hardwood. However, in the aftermath of the longest spruce bark beetle outbreak in North America, not all spruce is regenerating back to spruce or converting to hardwood. Much of what was mature white and Lutz spruce forest on the southern peninsula is now Calamagrostis grasslands with few spruce seedlings. He reports that climate-envelope models predict deforestation on parts of the Kenai, and spring fires may be the mechanism by which a new grassland ecosystem is maintained in what used to be a transitional boreal forest.

◆ **Moss, M. and L. Hermanutz. 2009.** Postfire seedling recruitment at the southern limit of lichen woodland. Canadian Journal of Forest Research, 2009, 39(12): 2299-2306, 10.1139/X09-150

Author abstract. Although fire is the primary mechanism driving regeneration in open black spruce (Picea mariana (Mill.) BSP) lichen woodland, there are limited data concerning the sources of seedling mortality across the range of burn severity. We monitored planted seedlings in areas of high and low burn severity in Terra Nova National Park (Newfoundland, Canada) to determine sources and patterns of mortality of black spruce seedlings among burn treatments following a recent burn (2002). The importance of herbivory by small mammals as a source of seedling mortality was evaluated using small cages that excluded voles and non-native snowshoe hare. Overall seedling mortality was high (79%) in all areas; mortality was similar in areas of low (73%) and high (76%) burn severity, and highest in edge areas adjacent to closed-canopy forest (90%). Drought, rather than herbivory, was the most common cause of mortality during the first two seasons following germination. Seedling mortality at the southern edge of the lichen woodland was comparable to that found in other studies, but sources differed, emphasizing the spatially variable nature of mortality. Based on the level of seedling recruitment, our results suggest lichen woodland will return at this site.

◆ **Natcher, D.C., M. Calef. O. Huntington, S. Trainor, H.P. Huntington, L. DeWilde, S. Rupp. and F.S. Chapin III. 2007.** Factors Contributing to the Cultural and Spatial Variability of Landscape Burning by Native Peoples of Interior Alaska. *Ecology and* Society 12(1): 7. [online] URL: http://www.ecologyandsociety.org/vol12/iss1/art7/Research

Author abstract. Although wildfire has been central to the ecological dynamics of Interior Alaska for 5000 yr, the role of humans in this dynamic is not well known. As a multidisciplinary research team, together with native community partners, we analyzed patterns of human-fire interaction in two contiguous areas of Interior Alaska occupied by different Athabaskan groups. The Koyukon in the western Interior considered fire a destructive force and had no recollection or oral history of using fire for landscape management. Low lightning-strike density and moist climate constrained the effects of lightning fires, and a subsistence dependence on salmon, a relatively predictable resource, resulted in a trilocal residency pattern. In this environment the occurrence of wildfire would have negatively impacted territorial use and the exploitation of wildlife resources. In contrast, the Gwich'in of the eastern Interior actively used fires to manage the landscape. The Gwich'in territory experienced a higher lightning-strike density and a corresponding increase in wildfire activity. The Gwich'in showed greater mobility in hunting moose and caribou, their less spatially predictable subsistence resources, which enabled them to avoid and/or target a range of habitats affected by wildfires. The contrasts between these two neighboring Athabaskan groups indicate different uses and views of wildfire that are derived from their cultural adaptation to local biophysical and ecological settings. These findings call into question the commonly held view that native peoples of North America pervasively and near universally modified landscapes through the use of fire.

◆ **Paragi, T.F., and D.A. Haggstrom. 2007**. Short-term responses of aspen to fire and mechanical treatments in Interior Alaska. Northern Journal of Applied Forestry 24:153-157.

Author abstract: Fire suppression and limited timber markets presently hinder maintenance of the early successional broad-leaved forest for wildlife habitat near settlements in interior Alaska. During 1999 –2003, we evaluated the efficacy of prescribed burning, felling, and shearblading (with and without debris removal) to regenerate quaking aspen (*Populus tremuloides*). Treatments were conducted largely during the dormant period for aspen: prescribed burns in mid-May and mechanical treatments in late August through early April. Prescribed burns on loess hills produced 40,900 –233,000 stems/ha by the second growing season. Low relative humidity, slope of more than 10°, southerly aspect, and juxtaposition to open areas produced fire behavior adequate to ensure top killing and vigorous sprouting response. Felling by chainsaw on loess hills produced 34,800–89,800 stems/ha, whereas dozer shearblading on glacial outwash (loam over gravel) produced 74,200 –209,200 stems/ha (cleared portions and windrows combined) and a sandy loam floodplain produced 31,400–64,800 stems/ha. Pushing debris into windrows or scraping thick moss allowed warmer soils and produced greater sprouting on cleared sites relative to sections where debris or moss remained. Mechanical treatments were 25–75% of current prescribed fire costs, but debris accumulation may hinder access by browsing species and attract terrestrial predators of gallinaceous birds.

Notes (Paragi): The objective for aspen stem density based on creating brood rearing habitat for ruffed grouse in the Great Lakes region was 30,000 stems/ha (12,500/ac) by the end of the 2nd

growing season (Gullion 1984). This browse abundance would also be highly attractive to moose and snowshoe hares and function to shade grass in the understory.

"We observed intense browsing (proportions of total stems browsed and individual stems removed) by moose in some areas of all treatment types, particularly the first winter after the initial growing season. However, debris jackstraws sometimes more than 1 m high likely contributed to reduced browsing observed with increasing distance inside aspen felling sites at Nenana Ridge (Nichols 2005)… We now design aspen treatments to be 8 ha or more to reduce browsing pressure, the per-area costs of mechanical treatments because of fixed costs of equipment mobilization, and the proportional loss of treatment area in prescribed burns because of fire control lines and related burn characteristics" (p. 156).

◆ **Perry, D.J. and J. Bousquet. 2001**. Genetic diversity and mating system of post-fire and post-harvest black spruce: an investigation using codominant sequence-tagged-site (STS) markers. Canadian Journal of Forest Research, 2001, 31(1): 32-40, 10.1139/x00-137

Author abstract. cDNA-based sequence-tagged-site (STS) markers were used to examine the genetic composition of three mature, layer-origin populations of black spruce (*Picea mariana* (Mill.) BSP), which were the result of logging operations in the first half of the 20th century, and compare them with four mature, seedling-origin populations that regenerated naturally following fire. The amount of STS-marker variation revealed in these populations was very similar to that previously observed in a rangewide panel of black spruce trees. There was little differentiation among populations, and no significant differences in heterozygosities, numbers of alleles, or fixation indices were evident between layer-origin and fire-origin stands. Likewise, when mating-system parameters were estimated in one population of each of these two types, no significant differences were found; outcrossing was essentially complete with no evidence of mating among relatives. The estimated correlation of paternity within progeny arrays was about 17 and 13% in the fire-origin and layer-origin stands, respectively, but again the observed difference was not statistically significant. At least at the current scale of sampling, silvicultural practices that result in stand replacement by layer-origin advance regeneration appear not to have had negative impact upon the genetic diversity or level of inbreeding in second-growth black spruce stands.

◆ **Peters**, V.**S., S.E. Macdonald, and M.R.T. Dale. 2005.** The interaction between masting and fire is key to white spruce regeneration. Ecology 86(7) 1744–1750

Author abstract. We used the mast-seeding tree *Picea glauca* (white spruce) to examine whether the timing of mast years relative to fire had a lasting effect on the density and timing of regeneration. We studied 17 fires that occurred in mast years and in years with low cone production between 1941 and 1994. Trees were carefully aged by crossdating procedures. Over the 59-yr period studied, there was significantly more regeneration after fires that occurred in mast years than after fires that occurred in years of low cone production. Spruce density was significantly lower after fires that occurred 1–3 years before a mast year than after fires during mast years. The cohort of trees that regenerated in the first mast year after a fire was critical to white spruce regeneration for fires that occurred 0–1 year before a mast year, but mast years occurring three or more years after a fire contributed few recruits. Our results suggest that masting is a key process that interacts with fire to shape stand composition in boreal mixedwoods. For species like white spruce, for which establishment is linked to disturbance, masting may have a contingent, historical effect on succession and landscape structure.

◆ **Potkin, M. 1997.** Fire history disturbance study of the Kenai Peninsula mountainous portion of the Chugach National Forest. Unpublished report. USDA Forest Service, Chugach National Forest, Anchorage, Alaska.

Author abstract. Forests in the vicinity of the Kenai Peninsula portion of the Chugach National Forest are of special ecological interest because of their transitional nature between coastal and interior forest types. The Continental Interior boreal forest and Maritime Pacific coast ecological regions merge on the Forest. Fire has historically been present in this century in the Kenai Mountains but whether fire is the important disturbance process creating structural and landscape diversity within this ecosystem is unknown. This report describes three distinct periods of fire frequency - prehistoric (pre 1740), settlement (1741-1913), and post-settlement (1914-1997). Fire reports on the Forest from 1914-1997 were summarized and attributed into a GIS data base documenting fire occurrences for the post-settlement period. A historic fire map was generated for known disturbance burn polygons. A historic land classification document containing maps and photographs, reveals widespread fire disturbances at the turn of the century, settlement period. The present study examined the fire history disturbances of three isolated mature forest areas to reconstruct the age distributions of living trees. Twenty-four historic burns were also examined, future work will reconstruct the age distributions of living trees sampled. Radiocarbon dates of soil charcoal were collected under mature forest stands to document pre-historic fire occurrences. Within the historic burns, remnants of older stumps and isolated residual trees reveal mature forests existed prior to disturbance. Needleleaf forests adjacent to these historic burns have ages greater than 200 ybp. The ages of living Lutz spruce and mountain hemlock within the mature forests sampled are greater than 200 ybp, subsurface soil charcoal is greater than 500 ybp. Although abiotic disturbances such as wind, snow avalanche, landslides, glacial recession, and flooding have been recognized for the important ways in which they influence the pattern of vegetation and tree recruitment on the Forest, the role of fire is now recognized as an important disturbance process over many millennia in this transitional climate. The historical records of fires and tree ages, together with the present mature forests and beetle kill fuel loads, suggest that the next interval of stand-regenerating fires is near. *[Compiler note: Table 1 includes notes on post-fire recruitment.]*

◆ **Rees, D.C., and G.P. Juday. 2002.** Plant species diversity and forest structure on logged and burned sites in central Alaska. *Forest Ecology and Management* 155 (1-3): 291-302.

Author abstract. Natural fires and logging are two of the main disturbances affecting upland boreal forest in Alaska. The objectives of this study were to determine whether logged sites differ from burned sites in (1) overall plant species richness, 2) successional trajectories, and (3) species diversity at particular stand structural development stages. We compared plant species diversity on sites burned in natural fires to sites that were logged and not subsequently burned in central Alaska. We sampled 12 logged and 12 burned former upland white spruce (Picea glauca (Moench) Voss) forests in four stand development stages representing stand initiation (stage A), early stem exclusion (stage B), understory reinitiation (stage Q, and mature hardwood (stage D) stages. In this study the dates of disturbance varied from 1990 to 1994 in stage A, 1978 to 1983 in stage B, 1957 to 1965 in stage C, and 1900 to 1920 in stage D plots. All sites were similar in slope, aspect, and soil type. Vascular plants were identified to the species level (except for certain willows) and bryophytes and lichens were identified to the level of presumptive (usually unknown) species within family groups. Organic layer thickness was significantly greater on logged sites compared to burned sites overall and at each stage. Burned sites (all stages combined) supported more species (146) than logged sites (I 11), and more species at each stand development stage. Burned plots in stages A and B supported abundant cover of a few apparent fire specialist species (Ceratodon purpurcus (Hedw.) Brid., Marchantia polymorpha L. and Leptobryum pyriforme (Hedw.) Wils.) that were present in only minor amounts on logged sites. Burned plots exhibited higher species turnover from stage to stage and among all stages than logged plots. Species dominant in burned stage A plots were nearly absent in burned stage C and D plots, while logged stage A dominants, which were common mature forest species, increased in each subsequent stage. We compared floristic similarity between our disturbance plots and mature upland white spruce stands in Bonanza Creek Long-Term Ecological Research ALTER) site. Only five species found in the LTER dataset were not also present in this study, which suggests that nearly all species compositional change in our study area occurs during the first century after disturbance. Logged sites appear to begin and continue succession with a greater share of the original mature forest understory plants, while burned sites initiate succession with more distinctive and specialized plant species.

◆ **Schulze E.D., C. Wirth, D. Mollicone, and W. Ziegler. 2005.** Succession after stand replacing disturbances by fire, wind throw, and insects in the dark Taiga of Central Siberia. *Oecologia*, 146, 77–88.

Author abstract. The dark taiga of Siberia is a boreal vegetation dominated by Picea obovata, Abies sibirica, and Pinus sibirica during the late succession. This paper investigates the population and age structure of 18 stands representing different stages after fire, wind throw, and insect damage. To our knowledge, this is the first time that the forest dynamics of the Siberian dark taiga is described quantitatively in terms of succession, and age after disturbance, stand density, and basal area. The basis for the curve-linear age/diameter relation of trees is being analyzed. (1) After a stand-replacing fire Betula dominates (4,000 trees) for about 70 years. Although tree density of Betula decreases rapidly, basal area (BA) reached >30 m2/ha after 40 years. (2) After fire, Abies, Picea, and Pinus establish at the same time as Betula, but grow slower, continue to gain height and eventually replace Betula. Abies has the highest seedling number (about 1,000 trees/ha) and the highest mortality. Picea establishes with 100-400 trees/ha, it has less mortality, but reached the highest age (>350 years, DBH 51 cm). Picea is the most important indicator for successional age after disturbance. Pinus sibirica is an accompanying species. The widely distributed "mixed boreal forest" is a stage about 120 years after fire reaching a BA of >40 m2/ha. (3) Wind throw and insect damage occur in old conifer stands. Betula does not establish. Abies initially dominates (2,000-6,000 trees/ha), but Picea becomes dominant after 150-200 years since Abies is shorter lived. (4) Without disturbance the forest develops into a pure coniferous canopy (BA 40-50 m2/ha) with a self-regenerating density of 1,000 coniferous canopy trees/ha. There is no collapse of old-growth stands. The dark taiga may serve as an example in which a limited set to tree species may gain dominance under certain disturbance conditions without ever getting monotypic.

◆ **Shenoy, A., J. F. Johnstone, E. S. Kasischke, and K. Kielland. 2011.** Persistent effects of fire severity on early successional forests in interior Alaska. Forest Ecology and Management 261:381–390.

Author abstract. There has been a recent increase in the frequency and extent of wildfires in interior Alaska, and this trend is predicted to continue under a warming climate. Although less well documented, corresponding increases in fire severity are expected. Previous research from boreal forests in Alaska and western Canada indicate that severe fire promotes the recruitment of deciduous tree species and decreases the relative abundance of black spruce (*Picea mariana*) immediately after fire. Here we extend these observations by (1) examining changes in patterns of aspen and spruce density and biomass that occurred during the first two decades of post-fire succession, and (2) comparing patterns of tree composition in relation to variations in post-fire organic layer depth in four burned black spruce forests in interior Alaska after 10–20 years of succession. We found that initial effects of fire severity on recruitment and establishment of aspen and black spruce were maintained by subsequent effects of organic layer depth and initial plant biomass on plant growth during post-fire succession. The proportional contribution of aspen (*Populus tremuloides*) to total stand biomass remained above 90% during the first and second decades of succession in severely burned sites, while in lightly burned sites the proportional contribution of aspen was reduced due to a 40-fold increase in spruce biomass in these sites. Relationships between organic layer depth and stem density and biomass were consistently negative for aspen, and positive or neutral for black spruce in all four burns. Our results suggest that initial effects of post-fire organic layer depths on deciduous recruitment are likely to translate into a prolonged phase of deciduous dominance during post-fire succession in severely burned stands. This shift in vegetation distribution has important implications for climate-albedo feedbacks, future fire regime, wildlife habitat quality and natural resources for indigenous subsistence activities in interior Alaska.

◆ **Wardle, D.A., O. Zackrisson, and M.-C. Nilsson. 1998.** The charcoal effect in Boreal forests: mechanisms and ecological consequences. Oecologia 115(3): 419-426.

Author abstract. Wildfire is the principal disturbance regime in northern Boreal forests, where it has important rejuvenating effects on soil properties and encourages tree seedling regeneration and growth. One possible agent of this rejuvenation is fire-produced charcoal, which adsorbs secondary metabolites such as humus phenolics produced by ericaceous vegetation in the absence of fire, which retard nutrient cycling and tree seedling growth. We investigated short-term ecological effects of charcoal on the Boreal forest plant-soil system in a glasshouse experiment by planting seedlings of *Betula pendula* and *Pinus sylvestris* in each of three humus substrates with and without charcoal, and with and without phenol-rich *Vaccinium myrtillus* litter. These three substrates were from: (1) a high-productivity site with herbaceous ground vegetation; (2) a site of intermediate productivity dominated by ericaceous ground vegetation; and (3) an unproductive site dominated by *Cladina* spp. Growth of *B. pendula* was stimulated by charcoal addition and retarded by litter addition in the ericaceous substrate (but not in the other two), presumably because of the high levels of phenolics present in that substrate. Growth of *P. sylvestris*, which was less sensitive to substrate origin than was *B. pendula*, was unresponsive to charcoal. Charcoal addition enhanced seedling shoot to root ratios of both tree species, but again only for the ericaceous substrate. This response is indicative of greater N uptake and greater efficiency of nutrient uptake (and presumable less binding of nutrients by phenolics) in the presence of charcoal. These effects were especially pronounced for *B. pendula*, which took up 6.22 times more nitrogen when charcoal was added. Charcoal had no effect on the competitive balance between *B. pendula* and *P. sylvestris*, probably due to the low intensity of competition present. Juvenile mosses and ferns growing in the pots were extremely responsive to charcoal for all sites; fern prothalli were entirely absent in the ericaceous substrate unless charcoal was also present. Charcoal stimulated active soil microbial biomass in some instances, and also exerted significant although idiosyncratic effects on decomposition of the added litter. Our results proved clear evidence that immediately after wildfire fresh charcoal can have important effects in Boreal forest ecosystems dominated by ericaceous dwarf shrubs, and this is likely to provide a major contribution to the rejuvenating effects of wildfire on forest ecosystems.

◆ **Weir, J.M.H. and E.A. Johnson. 1998.** Effects of escaped settlement fires and logging on forest composition in the mixedwood boreal forest. Can. J. For. Res. 28: 459-467.

Author abstract: The southern edge of the boreal forest in central Saskatchewan, Canada, has had its forest composition changed in the first decades of this century, primarily by logging and escaped fires from adjacent agricultural clearance. Three timber berths were established in 1884 within and immediately adjacent to the present southern half of Prince Albert National Park (established in 1927). These timber berths were selectively logged for saw timber between 1900 and 1918. Between 1907 and 1918, an average of 70 trees per hectare were removed by selective logging. Most of these trees were white spruce (*Picea glauca* (Moench) Voss). Since logging companies were required to remove all merchantable trees with a basal diameter greater than 25 cm, it is estimated that between 28 and 54% of the canopy trees were removed. Between 1883 and 1942, 81% of the timber berths were burned two or more times by crown fires that spread through the study area from adjacent agricultural clearances 30 km or more away. By 1945, agricultural clearance was largely complete and the clearance-caused fires stopped. The changes in tree composition were determined by transition probabilities between forest surveys taken in 1883 and 1994. Forests subjected to short-interval, clearance-caused fires but no logging were significantly reduced in their abundance of sexually reproducing trees such as white spruce, but increased in trees with either vegetative reproduction (i.e., underground stems, not just basal sprouts) or serotinous cones, such as aspen (*Populus tremuloides* Michx.) and jack pine (*Pinus banksiana* Lamb.), respectively. Transition probabilities for forests experiencing both short-interval, clearance-caused fires and logging reveal an even more marked compositional change in this direction.

◆ **Zasada, J.C. 1985.** Production, dispersal, and germination of white spruce and paper birch and first-year seedling establishment after the Rosie Creek Fire. pp. 37 in: Early results of the Rosie Creek Fire Research Project 1984. G.P. Juday and C.T. Dyrness, eds. Univ. of Alaska Fairbanks Agric. and For. Res. Exp. Sta. Misc. Publ. 85-2. 46 pp.

Compiler excerpt. After a 1-year study of seed regeneration of interior Alaska trees on productive upland sites in the Rosie Creek Fire, the most notable observations were:
1. The quantity of white spruce seedfall at 50 m (160 ft) along the transect into the fire was less than 20 percent of the within-stand seedfall in the source area; it was less than 10 percent at 100

m. Dispersal of birch seed was as high as 40 percent at 50 m but was less than 10 percent at 100 m.

2. Most seedlings occurred on seedbeds with an ash and/or organic layer depth of 2.5 cm (1 inch) or less; however, on sites where a good seed source was nearby, spruce and birch seedlings were found on organic seedbeds more than 5 cm deep. Observations on seedbed preference need to be expanded so the full range of conditions under which seedling establishment occurs can be determined.

3. Distribution of white spruce and birch seedlings in the Rose Creek burn did not necessarily follow the pattern that would be expected had seed been the only factor limiting regeneration. These results point out the importance of seedbed conditions and other biological variable that interact with seedfall in determining success of regeneration.

4. This fire occurred at about the time of white spruce pollination and the production of viable seeds by fire-killed trees was not expected. However, trees which were dead at the end of the summer of 1983 due to severe burning of the roots and lower bold produced significant quantities of viable seeds. Trees which had all or part of their crowns burned or scorched fby the fire did not produce seeds. Seeds produced by the above-mentioned trees are essential for rapid regeneration of white spruce and salvage of these trees should be delayed until after seed has been dispersed.

◆ **Zasada, J.C., R.A. Norum, R.M. Van Veldhuizen, C.E. Teutsch. 1983.** Artificial regeneration of trees and tall shrubs in experimentally burned upland black spruce/feather moss stands in Alaska. CJFR 13(5): 903-913, 10.1139/x83-120

Author abstract. Fall seed-dispersing species, birch (*Betula papyrifera* Marsh.), alder (*Alnus crispa* (Ait.) Pursh), and black spruce *Picea mariana* (Mill.) B.S.P.), and summer-seeding species, aspen (*Populus tremuloides* Michx.), balsam poplar (*P. balsamifera* L.), feltleaf willow (*Salix alaxensis* (Anderss.) Cov.), Scouler willow (*Salix scouleriana* Barratt), and Bebb willow (*Salix bebbiana* Sarg.), were artificially sown on seedbeds created by experimental burning in the upland black spruce/feather moss forest types in interior Alaska. At least 40% of the seeds dispersed in the fall had germinated before dispersal of summer seeds began. Germination occurred on moderately and severely burned seedbeds but not on scorched and lightly burned surfaces. Seedling survival occurred almost exclusively on severely burned surfaces. After 3 years, 82% of the plots containing some severely burned surfaces and sown with seeds from species seeded in the fall were stocked whereas 32% of the plots sown with species seeded in the spring and with the same seedbed condition were stocked.

Section 6

WILDLIFE-REFORESTATION INTERACTIONS

SUMMARY

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Background: Birds and mammals can enhance or inhibit tree regeneration in boreal forest. These interactions may be considered either positive or negative depending upon specific regeneration and silvicultural objectives for a given tree species (Cox 1938). Below we describe forest-wildlife interactions most germane to tree regeneration in Alaska boreal forest. Our literature review included analogous relationships in Eurasia boreal forests.

***Herbivory*:** Mammals remove leaves and bark, which can predispose trees to stress, reduce height and radial growth, cause physical defect, allow fungal entry, or cause direct mortality by girdling or breakage (Gill 1992a). Snowshoe hares (*Lepus americanus*) can heavily browse or girdle young coniferous and deciduous trees, particularly during hare population highs (Radvanyi 1987). Moose (*Alces alces*) in Alaska feed primarily on shrubs and young deciduous trees by stripping leaves in summer and fall and browsing dormant twigs of current annual growth in winter, sometimes breaking the apical stem to reach higher twigs that contain lower concentration of anti-herbivory compounds. Intensive moose browsing can reduce deciduous tree recruitment (Andrews 1998) and potentially hasten succession of mixed forest to conifer. Moose herbivory during stand initiation can influence succession through differential mortality on preferred species and reduction of soil nutrients through reduced litter fall (Persson et al. 2005) with ultimate potential to reduce stumpage. Voles in the genus *Microtus* are most prevalent in grassy habitats and consume bark of young coniferous and deciduous trees, often beneath the snow surface (Gill 1992b). Vole herbivory can be extensive during abundance peaks (Huitu et al. 2009, Sullivan and Sullivan 2010). However, based on prevalence in the literature, vole herbivory seems less important to boreal forest dynamics in North America than snowshoe hare herbivory.

Predator Diversity (insectivores and carnivores): Stressors such as fire, drought, or flooding can weaken plant defenses against insects. Avian insectivores can sometimes mitigate irruptions of insects and allow an increase in plant biomass while reducing leaf damage and plant mortality in a wide array of habitats (Mooney et al. 2010, Mäntylä et al. 2011). Woodpeckers (*Picoides* spp.) play a significant role in regulating conifer bark beetles (*Dendroctonus* and *Ips* spp.) populations as evidenced from empirical observations, exclosures, and modelling experiments (Fayt et al. 2005). Woodpeckers and native bark-foraging birds can be effective predators of invasive insects (Flower et al. 2014). In addition, there is evidence that increased diversity of insectivorous small mammals increases their collective predatory effectiveness against insect irruptions (Holling 1959). Mammalian herbivores like hares or voles are in turn important prey to a range of avian and mammalian predators in boreal ecosystems. Predation is a major factor influencing hare abundance (Krebs et al. 2001), which potentially affects tree regeneration.

Dispersal of mycorrhizal fungi: Small mammals, including voles and flying squirrels, are obligate dispersers of hypogeous fungi that are associated with tree root mycorrhizae (e.g. Jacobs and Luoma 2008, Smith 2007). Such fungi play key roles in regeneration. For example, seedling establishment, nutrient uptake, and tree resilience and vitality of *Pinus* in the Pacific Northwest and Eurasian boreal are linked to mammal-dispersed spores (Jacobs & Luoma 2008, Schickmann et al. 2012).

Recent investigations specific to interior Alaska have revealed four important (though independent) facts. First, soil fungi are positively associated with regeneration in birch, poplar and spruce (stem diameter and/or shoot mass; Bent et al. 2014). Second, northern red-backed voles (*Myodes rutilus*), which dominate rodent abundance, consume the greatest proportion of fungi compared to any other vole species (Baltensperger 2015). Third, hypogeous fungi, which are obligately dispersed by mammals, occur in both mature white spruce and mixed deciduous stands (Laursen 1985; L. Taylor, unpubl. data). Fourth, although Alaskan soils exhibit a diversity of fungi (Taylor et al. 2010, 2014), roots of birch, poplar and spruce host a common "complex" of fungal species (Bent et al. 2014), which requires an inoculum of spores be present in the soil (Hewitt et al., 2013) .

Management considerations: Once silvicultural objectives are identified, forest and wildlife managers can make informed decisions on how to promote site-specific regeneration. Recommendations may include techniques to optimize habitat that will promote specific wildlife-based outcomes or advice on means to directly or indirectly manage herbivore abundance. Key concepts follow, including spatial scale of measurements and effects.

Herbivory: Herbivory risk is strongly influenced by habitat within a temporal and spatial context (Reimoser and Gossow 1996, Cadenesso and Picket 2000). Wildlife professionals track cycles of small mammal and snowshoe hare abundance in selected areas that provide a coarse index of risk for planting schedules and existing regeneration. However, herbivory "risk" is relative, because peaks in herbivore abundance could achieve desired pre-commercial tree thinning in areas where seed crops are expected to result in overstocking. With regard to spatial context, small irregular-shaped logging units within a matrix of mature forest are likely to provide browsing attraction to moose because of abundant browse closely adjacent to forest cover (Weixelman et al. 1998). Reducing dense grass will reduce preferred habitat for *Microtus* voles and potentially their abundance (Sullivan and Sullivan 2010), but reduction in girdling may not be ensured where snow cover provides concealment from predators (Hansson 1986). Dense understory of young growth near mature cover provides optimal habitat for snowshoe hares (Hodges 2001), so increasing distance to cover may reduce herbivory (Radvanyi 1987). Feeding preferences of moose for some non-native trees (e.g., Scots pine, *Pinus* ***sylvestris***) may complicate production until larger plantings are feasible to reduce their rarity on the landscape. Rarity can predispose plants to browsing for herbivores that minimize toxic satiation from anti-herbivory compounds in vegetation (Bryant et al. 1991).

Predator Diversity: To facilitate predation on deleterious insects and mammalian herbivores, forests can be managed to promote features that favor predators. Forest managers can configure managed landscapes and structure stands to achieve this goal. Retention of intact forest "islands" containing late-seral features may support predators of smaller herbivores such as insects or hares. Late-seral features such as snags can promote predator fitness by providing bark-substrate for insectivores, roosts and hunting perches for raptors, and nesting cavities for woodpeckers or martens (*Martes americana*; Bunnell et al. 2002). Within a harvest unit, late-seral features within islands of habitat are less vulnerable to windthrow than individual isolated features. Promoting habitat for herbivore predators and fungal dispersers can function to "retain ecological processes, functions and patterns to provide resilience to short-term stresses and adaptation to long-term change" (Society of American Foresters 1993:14).

Dispersal of mycorrhizal fungi: Forest practices can affect the ability of small mammals such as red-backed voles to successfully disperse fungal spores associated with tree mycorrhizae. We believe experiments in the Pacific Northwest are likely to apply to interior Alaska, where red-backed voles are most abundant and known to consume large amounts of fungi. Specifically, vole feces contained significantly fewer spores when tree retention within a harvest unit was less than 40%. However, this negative effect was reduced if trees were retained as "aggregate islands," rather than dispersed evenly within the harvest unit (Jacobs & Luoma 2008). This scenario further supports a landscape approach of maintaining adequate islands of habitat to enhance predator diversity, while providing for soil inoculation with mycorrhizal fungi.

Notes accompanying the following references are analysis from Tom Paragi, ADF&G.

REFERENCES

◆ **Andrews, J.H. 1998.** The impact of moose browsing on Populus in the Susitna Valley, southcentral Alaska . Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 125 pp.

Author abstract. Twenty balsam poplar *(Populus balsamifera* L.) and twenty quaking aspen *(Populus tremuloides* Michx.) sites were sampled to determine the impact moose browsing has upon early tree growth and forest stand structure. Dominant heavily browsed stems from each of the 20 plots per site were sampled for top height, stump diameter, age, and stem quality and compared with available dominant, unbrowsed stems. Remaining stems in the plots were tallied according to species, 0.5 m height class, browse intensity, and mortality. Unbrowsed tree heights were 2.1-3.5 times taller and diameters were 1.4-2.6 times greater than heavily browsed stems within the same age class. Preferred browse species stems taller than 0.5 m had browse damage greater than 91.0 percent. The occurrence of stain and decay were twice as great in heavily browsed stems as in unbrowsed stems. The intensity of browsing and reduced growth can extend the rotation age or favor dominance of non-browse species.

Notes: Sampling occurred in Game Management Units 14A (a few sites in Matanuska Valley) and 14B in proximity to road access, but date of field work and moose density were not noted [assume 1996-97; moose were ca. 3.5/mi^2 in 14A and 1.5-2.0/mi^2 in 14B per ADF&G]. Author distinguished succession in phases: establishment (initial stocking and composition, too short to be affected by moose [but not hares] and shrub-sapling (where most moose damage occurs). A total of 20 aspen and 20 poplar sites were sampled, with spatial resolution noted to quarter section. Each site had one transect of 20 circular plots (100 ft^2); this plot scale means 1 spruce per plot is approx. 10 ft spacing for 435 crop trees/ac (stocking standard). Sampling characterized crop trees (tallest per plot, assumed to become dominant in canopy) and escape trees (free-to-grow >4 m, no longer subject to repeated browsing). The appendix contains stem (>15 cm) count data of unbrowsed, browsed by hare or moose, and dead by each of 4 "species" (*Betula papyrifera,* 2 *Populus, Salix* "spp.") plus site characteristics (mean crop and escape tree heights and diameters, age range, stocking). Average age for all crop and escape *Populus* were <25 years. Only 11 of the 40 sites had escape trees, and only 1 of the 11 sites had 20 or more escape trees. Only 3 of the 800 crop tree plots contained an escape tree, indicating the heavy level of browsing (equal preference by 0.5 m height class among the 4 "species"). Author noted the challenge of discerning proportional mortality influence from browsing and overstory competition for light and resources. "The open canopy condition caused by moose browsing may prolong the period that the stand is suitable for moose browse… Because of continued browsing pressure, it is not possible to predict [using growth and yield] the age at which *Populus* stands will be 'free to grow'" (p. 37).

◆ **Angell, A. C. and K. Kielland. 2009.** Establishment and growth of white spruce on a boreal forest floodplain: interactions between microclimate and mammalian herbivory. Forest Ecology and Management 258:2475-2480.

Author abstract. White spruce (*Picea glauca* (Moench) Voss) is a dominant species in late-successional ecosystems along the Tanana River, interior Alaska, and the most important commercial timber species in these boreal floodplain forests. Whereas white spruce commonly seed in on young terraces in early primary succession, the species does not become a conspicuous component of the vegetation until after 60–80 years. To address what abiotic and/or biotic factors may explain the paucity of spruce in earlier stages of succession, we examined germination and growth of planted white spruce seedlings across an environmental gradient that included variation in soil physico-chemical properties in the presence and absence of mammal browsing. The effect of browsing pressure over the first four years after planting was most noticeable on the older terraces. Likewise, direct effects of hare browsing on spruce seedling mortality were only manifested at the oldest sites. Spruce germination and survival was inversely proportional to soil cation concentrations, which was largely controlled by temperature-driven evapotranspiration. High light intensities and high air temperatures significantly reduced seedling growth, whereas variation in soil moisture only explained a significant amount of variation in seedling survival. Temperatures within the needle clusters on terminal shoots reached values that adversely affect photosynthesis (>32 °C) on multiple occasions over the growing season. We conclude that the direct (temperature) and indirect (soil chemistry) effects of high insolation are major factors constraining spruce performance on early successional terraces, and that these effects can be significantly exacerbated by mammal browsing on associated deciduous vegetation.

Notes: "Our central hypothesis was that moose browsing on deciduous vegetation would have negative effects on white spruce seedling performance. In particular, we predicted that moose browsing would decrease canopy cover, resulting in increased radiation, needle temperature, and soil cation concentrations, which would decrease germination, seedling survivorship, and seedling growth" (p. 2476). A key finding was "…increased canopy cover of associated deciduous vegetation ameliorates conditions to enhance growth of spruce seedlings" (p. 2479). Moose browsing of willow reduced its height, allowing greater insolation to reach planted spruce seedlings and reduce spruce growth after 4 growing seasons. "Spruce seedling growth was positively related to increased biomass of associated willow vegetation, implying a more favorable microhabitat under such lower light conditions…"

This experiment was conducted during the low abundance phase of the snowshoe hare cycle. Variable browsing by hares and individual growth responses of spruce seedlings resulted in no significant treatment effect across a chronosequence of river terrace ages (1-12 yrs.). "Other experiments with planted spruce seedlings on the Tanana River floodplain have similarly shown high initial performance (in association with dense deciduous cover), but nearly zero survival after a decade, largely due to severe browsing by snowshoe hares … These observations suggest that the synchrony of masting in white spruce relative to the trajectory of the snowshoe hare cycle can have profound effects on natural generation of white spruce" (p. 2479).

◆ **Angelstam, P., P.-E. Wikberg, P. Danilov, W.E. Faber, and K. Nygren. 2000.** Effects of moose density on timber quality and biodiversity restoration in Sweden, Finland, and Russian Karelia. Alces 36:133-145. [M]

Author abstract. A long history of forest use and management in Sweden has promoted conifer- dominated forests at the expense of deciduous trees such as *Populus tremula, Salix caprea,* and *Sorbus aucuparia.* Moose *(Alces alces)* are a key species both with respect to the maintenance or biodiversity associated with these deciduous trees and to the production of good quality Scots pine *(Pinus sylvestris)* timber. For biodiversity there is a need to restore the deciduous forest component, which is also the preferred food of moose. If the moose/preferred food ratio is too high and hence browsing on the preferred tree species too intensive, this restoration can be difficult. To study the interactions between the abundance of preferred moose food, moose density, and damage to trees, it is necessary to include landscapes with a broader combination of food abundance and moose density than found just in Sweden. This is necessary as the landscape and management situation in Sweden is rather homogeneous, with the same policies concerning forestry and moose management having been implemented. To cover a wide range of relevant factors, a study covering 8 landscapes in Sweden, Finland, and Russian Karelia was carried out in autumn 1998. Damages on both preferred trees and Scots pine in pine-dominated stands were correlated to moose density. Damages were most severe in Sweden, intermediate in Finland, and least in Russian Karelia. Moose winter densities ranged from 1.7/km^2 in Sweden to 0.2/km^2 in Russia. The cover of preferred foods *(Populus/Salix/Sorbus)* increased 13-fold from Sweden to Russia. As a consequence, the proportion of severely damaged and dead individuals of the preferred species increased 36-fold from the least to the most affected landscape. Similarly, damages on Scots pine in pine-dominated stands ranged from 57% in Sweden to 7% in Russian Karelia. Unless damage by moose is reduced in Sweden in the landscapes that we studied, it is doubtful that deciduous vegetation can be maintained, thereby affecting biodiversity. Communication with stakeholders is essential if this socio-economic problem is to be resolved. One feasible model may be co-management case studies based on a holistic landscape view and objective inventory of perceived problems among all stakeholders.

Notes: The authors sought to describe variation in moose damage to tree species across a gradient of forage abundance and of moose density on winter range where moose are spatially concentrated. Density ranged from 0.5moose/mi^2 in Russia to 4.4/mi^2 in Sweden, averaged over 13 years to match average age of young stands measured for vegetation parameters. Damage of pine, spruce, birch, and aspen was measured as broken tops or cambium removal, whereas for aspen it was inability to reach free-to-grow status (e.g., all long shoots browsed or dead). Damage level in both plant species groups was positively correlated to moose density over the large landscape (Fig. 2). Expressing damage levels in a context of the "ratio of moose to forage" is a first step in mitigating damage, which requires reducing moose, increasing forage, or reducing availability of forage to moose. Practical considerations of calculating this ratio and implementing mitigation are discussed.

◆ **Baltensperger, A.P. 2015.** Detecting the effects of environmental change on Alaska's small mammal fauna using machine-learning-based geographic and isotopic niche modeling. Ph.D. dissertation, University of Alaska, Fairbanks. 182 p.

Author abstract. As anthropogenic climate change alters biomes, ecosystems, and wildlife communities, determining how the niche spaces of species will respond is vital for determining appropriate conservation policy that promotes biodiversity and species persistence. In Alaska, quantifications of dietary patterns and geographic distributions among small mammals (rodents and shrews) are incomplete. As a result, wildlife managers are often ill-equipped to adequately account for these ecologically important taxa. We used stable isotopes, open-access occurrence records, and machine learning methods to model the dietary and geographic niche spaces of 17 species of small mammals in mainland Alaska. We also calculated the degree of niche overlap among species to estimate potential competition among conspecifics for both food and space. Using "bio-blitz" sampling along two statewide megatransects, we detected small mammal species richness and collected stable isotope samples at 20 locations across Alaska. Stable isotope (δ15N and δ13C) mixing models were used to define dietary proportions for each species and to outline their fundamental and realized foraging niches. We created spatial distribution models for each species for the years 2010 and 2100 by applying machine learning methods to 4,408 unique occurrence records attributed with 27 and 33 environmental predictor variables, respectively.

Spatial relationships between co-occurring species helped to determine the dominant structure of small mammal community assemblages for both time periods. Land change analyses identified regions of species loss, persistence, or gain over time. Stable isotopes (δ15N and δ13C) of shrews, rodents, fungi, and herbaceous plants were also modeled spatially to create continuous baseline isoscape predictions for Alaska. Dietary niche models showed a high degree of fundamental niche overlap among species at the statewide scale, whereas realized niches were more segregated at the study area scale. This suggests that species may be plastic in their use of shared resources in order to avoid competition. Isoscape models highlighted mid-elevations in the Yukon-Tanana Uplands, Brooks Range foothills, and the Yukon-Kuskokwim Delta as isotopic 'hot-spots.' Isotope values were considerably higher than trophic baselines in these regions, indicating where small mammals may have been consuming more fungi than herbaceous plants. On average, 2010 distribution models accurately predicted the occurrence of species in the field 75% of the time, and a composite species richness model highlighted biodiversity hotspots (11-13 species) across the Yukon-Tanana Uplands and western Brooks Range.

Community assemblage analysis for 2010 parsed species into 5 main community groups: northern, cold climate, interior, continental, and southern, but membership to these communities remained largely unchanged by 2100. Individual distributions, however, were predicted to change dramatically by 2100 as members of the northern, cold-climate, and interior communities shifted northward, inland, and upward in elevation following moving climate envelopes. Regions such as southwest Alaska and the Seward Peninsula experienced projected declines in species richness, while the number of species inhabiting the western Brooks Range and Alaska Range were predicted to increase. Results indicated that while species assemblages were robust in their organization over time, evidence of dietary niche plasticity suggests that communities may remain amenable to the addition of new species as shifting distributions overlap in new and unexpected patterns. Mid-elevations in topographically diverse regions such as the Brooks Range, Alaska Range, and the Yukon-Tanana Uplands will likely be centers for increased species richness and contact zones for novel species interactions in the future. These models, intended for public use, describe baseline conditions and future projections of small mammal niche ecology, with far-reaching implications for terrestrial trophic systems. We recommend that wildlife conservation and management decisions consider these models as we seek to promote biodiversity and the persistence of small mammal species across Alaska in a future altered by climate change.

◆ **Barbaro, L., Giffard, B., Charbonnier, Y., van Halder, I. and Brockerhoff, E. 2014.** Bird functional diversity enhances insectivory at forest edges: a transcontinental experiment. Diversity and Distributions 20:149-159. [L]

Author abstract. Aim: The role of bird–insect interactions in shaping bird distribution patterns at the landscape scale has been seldom investigated. In mosaic landscapes, bird functional diversity is considered to be an important driver of avian insectivory, but depends on forest fragmentation and edge effects from adjacent, non-forest habitats. In a transcontinental experiment, we investigated edge and landscape effects on bird functional diversity and insectivory in mosaic landscapes of mixed forests and open habitats.

Location: New Zealand and France.

Methods: We paired edge and interior plots in native forest fragments in New Zealand and native plantation forests in France. We sampled bird communities using point-counts and linear transects respectively and simultaneously quantified avian insectivory as the rate of bird attacks on plasticine models mimicking tree-feeding Lepidoptera larvae. The same seven life traits and attributes were compiled for French and New Zealand birds, including biogeographic origin, body mass, mobility, foraging method, adult diet, nest location and clutch size. Bird functional diversity was quantified on this multitrait basis by four indices: functional richness, evenness, divergence and dispersion. We used mixed models to test for the effects of forest edges, study area, surrounding landscape diversity and native forest cover on bird functional diversity and insectivory.

Results: We found higher bird functional richness at forest edges than interiors in New Zealand and lower functional richness at edges in France. However, bird functional evenness and divergence were significantly higher at forest edges in the two countries. Functional evenness and dispersion both increased with landscape diversity and evenness increased with native forest cover. Moreover, bird insectivory increased at forest edges with functional evenness, irrespective of the study area.

Main conclusions: We suggest that intermediate levels of forest fragmentation and edge effects increase avian insectivory in mosaic landscapes, through enhanced functional evenness and trait complementation within predatory bird assemblages.

Notes. This paper demonstrates that intermediate level fragmentation and edge effects can increase impact of insect predation by bird species within forests of France and New Zealand. A similar application could be derived by testing in Alaska.

◆ **Bent, E.B., P. Kiekel, R. Brenton and D. L. Taylor. 2011.** Root-associated ectomycorrhizal fungi shared by various boreal forest seedlings naturally regenerating after a fire in Interior Alaska and correlation of different fungi with host growth responses. Applied and Enviornmental Microbiology 77:3351-3359.

Author abstract. The role of common mycorrhizal networks (CMNs) in postfire boreal forest successional trajectories is unknown. We investigated this issue by sampling a 50-m by 40-m area of naturally regenerating black spruce (*Picea mariana*), trembling aspen (*Populus tremuloides*), and paper birch (*Betula papyrifera*) seedlings at various distances from alder (*Alnus viridis* subsp. *crispa*), a nitrogen-fixing shrub, 5 years after wildfire in an Alaskan interior boreal forest. Shoot biomasses and stem diameters of 4-year-old seedlings were recorded, and the fungal community associated with ectomycorrhizal (ECM) root tips from each seedling was profiled using molecular techniques. We found distinct assemblages of fungi associated with alder compared with those associated with the other tree species, making the formation of CMNs between them unlikely. However, among the spruce, aspen, and birch seedlings, there were many shared fungi (including members of the *Pezoloma ericae* [*Hymenoscyphus ericae*] species aggregate, *Thelephora terrestris*, and *Russula spp*.), raising the possibility that these regenerating seedlings may form interspecies CMNs. Distance between samples did not influence how similar ECM root tip-associated fungal communities were, and of the fungal groups identified, only one of them was more likely to be shared between seedlings that were closer together, suggesting that the majority of fungi surveyed did not have a clumped distribution across the small scale of this study. The presence of some fungal ribotypes was associated with larger or smaller seedlings, suggesting that these fungi may play a role in the promotion or inhibition of seedling growth. The fungal ribotypes associated with larger seedlings were different between spruce, aspen, and birch, suggesting differential impacts of some host-fungus combinations. One may speculate that wildfire-induced shifts in a given soil fungal community could result in variation in the growth response of different plant species after fire and a shift in regenerating vegetation.

Notes: This paper shows there are common networks or "communities" of fungi associated with roots of regenerating birch, aspen and black spruce boreal forests of Alaska. These root-associated fungi were associated with regeneration in all three tree species.

◆ **Bergqvist, G., R. Bergström, and M. Wallgren. 2014.** Recent browsing damage by moose on Scots pine, birch and aspen in young commercial forests – effects of forage availability, moose population density and site productivity. Silva Fennica 48 [online article #1077, 11 p.].

Author abstract: Moose browsing damage from the winter preceding the study (recent damage) on Scots pine, birch and aspen was examined in relation to forage availability, an index of moose population density and site productivity in young forests in the hemiboreal zone. Recent damage was observed for 4.1 ± 0.54% (mean ± SE; Scots pine), 16.8 ± 1.89% (birch) and 67.6 ± 13.76% (aspen) of the trees. A multiple regression with five independent variables explained 19% (Scots pine) 14% (birch) and 33% (aspen) of the variation in recent damage. Cover of Scots pine browse was the most important variable for predicting damage to Scots pine and accounted for 44% of the explained variation. When birch was overtopping pine there was a significant increase in damage to pine. Moose index was the only significant variable to explain recent damage to birch, and accounted for 64% of the explained variation. For aspen, damage was negatively correlated to coverage of Scots pine and birch browse, each variable accounting for 38% of the explained variation. For Scots pine, increasing the number of pines ha–1 and performing pre-commercial thinning in such a way that pines are not overtopped may be efficient ways of reducing damage proportions, whereas birch needs to be protected from moose (by a reduction of the moose population or otherwise) in order to escape damage. Increased amounts of Scots pine browse and birch browse may also reduce damage levels to aspen, according to this study.

Notes: There were 1.5-2.3 moose/mi^2 during this study in Sweden, which is relatively high compared with a density of 0.5-1.0 moose/mi^2 in Alaska boreal forest outside of areas where predators have been reduced below natural abundance and moose habitat has been enhanced by human disturbance. "Young" forest is not defined explicitly, but stands chosen for sampling had an average tree height of 1-4 m.

◆ **Bryant, J.P., F.D. Provenza, J. Pastor, P.B. Reichardt, T.P.Clausen, and J.T. du Toit. 1991.** Interactions between woody plants and browsing mammals mediated by secondary metabolites. Annual Review of Ecology and Systematics 22:431-446. [H]

Author conclusions. "Woody plants apparently rely on a chemically diverse array of specific secondary metabolites (rather than classes of secondary metabolites) as defenses against browsing by mammals. The effectiveness of these substances is primarily due to toxicity rather than digestion inhibition. A mammal's most flexible counter to phytotoxins is to learn to avoid intoxification through trial and error and from social models like mother. Through learning, mammals can determine which foods to eat and which to avoid, and how much food they can safely ingest. The amount of each food they can safely ingest is usually lower than the mammal's maintenance food requirement, so browsing mammals usually starve before they eat enough browse to be poisoned. The limits of food intake set by toxins suggest that interactions between woody plants and mammals can be analyzed as a functional response of a predator to its prey; the mammal is satiated when it is intoxified by the prey's chemical defenses. According to this hypothesis, a woody species should be most intensively browsed when it is rare. Heavily defended species should be more likely than poorly defended species to increase, because the detoxification capacity of mammals would be satiated sooner by heavily defended species. However, browsing does not always result in dominance by heavily defended species. If the biomass of a heavily defended species is too low to satiate the detoxification systems of mammals, browsing can eliminate the species. Selective browsing by mammals can greatly affect the composition of plant communities. Browsing usually favors an increase in unpalatable species that are heavily defended chemically. Moreover, once selective browsing encourages invasion by chemically defended species, invasion is likely to continue because the low nutrient requirements of these woody species let them persist in a nutrient-deficient environment.

Selective browsing can slow nutrient cycling in ecosystems dominated by woody plants, but it can accelerate nutrient cycling in ecosystems dominated by graminoids. A major reason for this difference is that woody plants have more chemical defenses than grasses do against mammalian herbivores. The chemical defenses that decrease the quality of woody species as food also make their litter poor quality as a substrate for decomposers." (p. 441-442).

◆ **Bunnell, F.L, I. Houde, B. Johnston, and E. Wind. 2002.** How dead trees sustain live organisms in western forests. Pages 291-318 *in* W.F. Laudenslayer, Jr., P.J. Shea, B.E. Valentine, C.P. Weatherspoon, and T.E. Lisle, Technical Coordinators. Proceedings of the symposium on the ecology and management of dead wood in western forests. USDA Forest Service General Technical Report PSW-GTR-181. 949 p. [M]

Author abstract. Dead wood contributes to biological richness as substrate, cavity sites, foraging sites, and shelter or cover. In the Pacific Northwest, 69 vertebrate species commonly use cavities, 47 species respond positively to down wood, and prevalence of both uses is related to natural fire regimes. Almost 80 percent of nests of weak excavators are in dead trees, strong excavators make greater use of live trees. Most bat roosts are in dead trees, whereas carnivores use mostly declining, living trees. Selection of both cavity and foraging sites is governed by decay patterns. Some species prefer large pieces of down wood. Management implications are discussed.

Notes. Paper has section on management implications (p. 303-305, summarized here only as bulleted recommendations verbatim):
"Our review suggests that if managers desire to sustain biodiversity they should:
- Ensure sustained provision of dying and dead wood
- Retain trees and snags of both hardwoods and favored conifer species (larch, Douglas-fir, ponderosa pine), particularly where hardwood species are not abundant. Avoid creating monocultures of less preferred species, such as lodgepole pine
- Retain a range of size and age classes of dead wood
- Ensure that some large trees or snags are retained
- Meet dead wood requirements for larger species in areas where the emphasis is not on intensive fiber production
- Don't do the same thing everywhere
- Limit salvage logging after forest fires"

The "Symposium on the Ecology and Management of Dead Wood in Western Forests" was convened to bring together forest researchers and managers to share the current state of knowledge relative to the values and interactions of dead wood to and in a functioning forest. Topics covered include the value of dead wood organisms in both terrestrial and aquatic habitats, the dynamics of dead wood, and ecological, industrial, and State and Federal land management agency perspectives. This information is immensely valuable to researchers and managers working with or managing dead wood in a variety of ecosystems.

◆ **Cadenasso, M.L., and S.T.A. Pickett. 2000.** Linking forest edge structure to edge function: Mediation of herbivore damage. Journal of Ecology 88:31-44. [L]

Author summary. "1. Forest edges, which are prominent features in the north-eastern United States landscape, may control the flux of organisms between forest and non-forest habitats. Previous studies have described edge structure rather than function, as deter- mined by interaction with such fluxes.
2. The function of the forest edge may be linked to the structure of its vegetation. We tested this hypothesis by experimentally altering the structure of the vegetation at two deciduous forest edges in Millbrook, New York, USA. Intact and thinned plots were established at each edge and we determined whether the structure of the edges influenced the flux of herbivores, as measured by herbivore damage to trans- planted tree seedlings.
3. Herbivore damage to seedlings at site 1 was affected by edge vegetation structure and by distance from the edge. The edge structure effect was due to herbivory by voles, which was significantly greater in the intact than in the thinned treatment. Regardless of treatment, voles damaged seedlings only on the edge and 30-40 m from the edge and did no damage in the forest interior (90-100 m), whereas deer damaged significantly more seedlings in the forest interior than on the edge. At site 2, where vole damage was concentrated on the edge, damage to seedlings was affected only by distance from the edge, not edge structure.
4. The two dominant herbivores, white-tailed deer and meadow voles, preferentially damaged different seedling species. In addition, tree seedlings browsed by deer resprouted more frequently than those clipped by voles. Our results suggest that both edge structure and distance from the edge influence herbivore activity and, as a result, influence the spatial arrangement, density and composition of populations of tree seedlings during regeneration in forest fragments."

◆ **Caldwell, L.R., K. Vernes, and F. Barlocher. 2005.** The northern flying squirrel (*Glaucomys sabrinus*) as a vector for inoculation of red spruce *(Picea rubens)* seedlings with ectomycorrhizal fungi. Sydowia 57:166-178. [M]

Author abstract. Mycophagous mammals excavate and ingest fruiting bodies (ascomata) of hypogeous ectomycorrhizal fungi and produce faeces containing numerous spores. To evaluate the significance of mycophagy to plant hosts we compared inoculation rate and degree of fungal development on red spruce *(Picea rubens)* seedlings treated >with (1) faeces of the northern flying squirrel *(Glaucomys sabrinus)* against seedlings treated with (2) ascospores of *Elaphomyces granulatus,* and (3) those grown in natural forest soil or (4) forest soil that had been rendered sterile. No seedlings growth in sterilised soil showed fungal colonization. Significantly more seedlings were colonized in natural forest soil (97.5 %) than in sterile soil treated with squirrel faeces (69.2 %) or fruiting body spores (27.5 %). Treatment with squirrel faeces produced significantly more colonization than treatment with fruiting body spores. Fungal development was significantly greater on seedlings grown in forest soil compared with other treatments, but did not differ significantly between squirrel faeces and fruiting body treatments. These results demonstrate that passage through the digestive tract of flying squirrels may enhance germination and maculation potential of fruiting body spores, although actively growing mycelium in forest soil may be the primary and most effective means by which seedlings develop mycorrhizae under natural conditions.

Notes. Sydowia is an international journal of mycology published in Austria. Authors collected squirrel feces and forest soil in Fundy National Park, New Brunswick and used commercial seed to germinate red spruce seedlings for the trials. "Our study provides experimental support to suggestions that northern flying squirrels and other mycophagous mammals are important and efficient dispersal vectors for ectomycorrhizal fungi and that ingestion of spores may be required for optimal spore germination" (p. 175).

◆ **Carey, A.B. 1995.** Sciurids in Pacific Northwest managed and old-growth forests. Ecological Applications 5:648-661. [M]

Author abstract. An understanding of the factors governing sciurid abundance in the Pacific Northwest is essential for prescribing forest management practices for second-growth forests where recovery of Spotted Owl (*Strix occidentalis*) populations and enhancement of bio-diversity are objectives. We compared results of companion studies of sciurids in western Washington and Oregon and examined patterns of abundance in relation to habitat elements on the Olympic Peninsula to elucidate governing factors and make recommendations for forest management. Regional contrasts show that *Glaucomys sabrinus* and *Tamias townsendii* in Douglas-fir forests in Oregon are 4 times more abundant than in western hemlock forests in Washington, and dietaries of *Glaucomys,* and the fungal communities that provide its food, are more diverse in Oregon than in Washington. *Glaucomys sabrinus* in old forests are 2 times more abundant than in young, managed forests without old-forest legacies (large live trees, large snags and large, decaying fallen trees), populations in young forests with old-forest legacies and with understory development may equal those in old growth. On the Olympic Peninsula, *Glaucomys sabrinus* abundance can be predicted by density of large snags and abundance of ericaceous shrubs. At least seven large snags/ha and well-distributed patches of dense shrubs (cover within patches >24% and patches covering 40% of the total area) are necessary for high densities of *Glaucomys sabrinus*. Abundance of *Tamias townsendii* reflects size of dominant tree and well-developed understories. Abundance of *Tamiasciurus douglasii* seems to reflect territoriality in concordance with food supply and was greatest where *Glaucomys* and *Tamias* were low in abundance. Patterns of abundance of the sciurids in old- and managed forests suggests that silvicultural manipulation of vegetation and creative snag or den-tree management could be used in a management strategy to accelerate the development of Spotted Owl habitat in areas where old growth is lacking.

◆ **Carey, A.B., and M.L. Johnson. 1995.** Small mammals in managed, naturally young, and old-growth forests. Ecological Applications 5:336-352 [M]

Author abstract. Forest managers in the Pacific Northwest are faced with new challenges of providing for all wildlife in managed forests. Our objective was to elucidate the factors governing the composition and biomass of forest floor mammal communities that are amenable to management. We sampled small mammal communities in forests of various management histories on the Olympic Peninsula and contrasted our results with those of other large studies in the Pacific Northwest. Forest floor mammal communities in forests >35 yr old in the Western Hemlock Zone of Washington and Oregon are composed of 5-8 characteristic species. These include *Sorex trowbridgii* (numerically the most dominant), one species each of *Clethrionomys*, the *Sorex vagrans* complex, and *Peromyscus,* and *Neurotrichus gibbsii*. Species composition changes from south to north, and the communities on the Olympic Peninsula contain two or three additional species compared to communities to the south. Communities in naturally re- generated and clearcutting regenerated (managed) young forests are similar in composition to those in old growth, old growth, however, supports 1.5 times more individuals and biomass than managed forest. Community diversity seems related to the south-north moisture-temperature gradient that is reflected in increased diversity of canopy conifers, development of forest floor litter layers, accumulation of coarse woody debris, and abundance of herbs, deciduous shrubs, and shade-tolerant seedlings (as opposed to understories dominated by evergreen shrubs). Previous work found few habitat variables that were good predictors of species abundance in natural young and old-growth stands. Naturally regenerated young stands had higher levels of coarse woody debris than old growth. Managed stands had much lower abundance of coarse woody debris and tall shrubs than old growth. Understory vegetation (herbs and shrubs) and coarse woody debris accounted for a major part of the variation in abundance of six of eight species in managed stands, but only two species in old growth. Management of Western Hemlock Zone forest for conservation of biodiversity and restoration of old-growth conditions should concentrate on providing multispecies canopies, coarse woody debris, and well-developed understories.

<u>Notes</u>. This research provided recommendations for maintaining small mammal abundance and diversity in managed forests of the Pacific Northwest. The specific recommendations do not directly apply to boreal forest of Alaska, but the high predictive power of coarse woody debris abundance and understory vegetation characteristics on small mammal abundance suggest functional relationships applicable in the boreal ecosystem. "Our empirical data suggest that 15-20% cover of coarse woody debris on the forest floor, well distributed across the site, would be adequate for most small mammals, whereas 5-10% cover would not allow the mammals to reach their potential abundances" (p. 347).

◆ **Collins, W. B. 1996.** Wildlife habitat enhancement in the spruce-hardwood forest of the Matanuska and Susitna River Valleys. Alaska Dept. of Fish and Game. Unpubl. Final Research Report 1 July 1990-31 December 1995. 58 pp.

Author summary. Timber harvest, scarification, burning, livestock grazing, various mechanical treatments and an herbicide were tested for their effectiveness in stimulating early successional hardwood production and enhancing wildlife habitat in boreal forest of south-central Alaska. In most mature boreal forest stands, a combination of overstory reduction and timely exposure of mineral soil was essential for promoting early successional hardwood growth and associated habitat enhancement. Prescribed burning was the most economical and natural means to accomplish this habitat enhancement, but its extent of application was limited by concerns of safety, land use, smoke emission and public perception. Clear cutting (with retention of seed trees) of mesic and dry sites was a viable alternative to burning, providing harvest and scarification was completed within one year before competing ground cover could exclude hardwood seedling establishment. I was unable to identify effective site preparations for wet stands which had been logged. Young hardwood stands (pole-sized or smaller) which had grown beyond the reach of moose were effectively rejuvenated by crushing a hydroaxing in winter. Legal and/or physical access were the greatest obstacles to habitat enhancement.

◆ **Collins, W. B., and C.S. Schwartz. 1998.** Logging in Alaska's boreal forest: creation of grasslands or enhancement of moose habitat. Alces, 34 (2): 355-374.

Author abstract: Timber harvest in Alaska's boreal forest can greatly enhance or severely reduce moose (*Alces alces*) habitat quality, depending on forest management objectives, timing and methods of harvest, and post-logging site preparation. Overstory removal associated with timely exposure of mineral soil favors establishment of early successional hardwoods important as moose browse. A combination of clear-cutting and soil scarification on mesic sites mimics fire, windfall, and fluvial erosion, important natural forces that drive regeneration of the boreal forest. When cut during dormancy, aspen (*Populus tremuloides*) and balsam poplar (*P. balsamifera*) regenerate prolifically by root and stump sprouting. However, harvest of paper birch (*Betula papyrifera*) or white spruce (*Picea glauca*) with little or no disturbance to the organic mat covering the forest floor often results in establishment of a long-lived herbaceous disclimax dominated by bluejoint reedgrass (*Calamagrostis canadensis*). This disclimax may persist for 25 to 100 years or more, limiting re-establishment of important deciduous browse species utilized by moose. With proper timber harvest, soil scarification, and good seedling establishment, carrying capacity for moose based upon forage supply can increase 20-45 fold (4-9 moose/km^2) over mature forest. Increases of this magnitude are also observed following wild fire. Estimates of carrying capacity following poor harvest practices with no scarification seldom exceed 0.2 moose/km^2, similar to that of mature forest. Properly regenerated clearcuts yield high quantities of moose browse for approximately 20 years following logging. We discuss the importance of appropriate timber harvesting practices relative to moose and the boreal forest ecosystem in Alaska.

Notes: These studies were conducted in the Matanuska and Susitna Valleys during 1990-95. Vegetative response was measured at 96 timber harvest sites, and separate trials evaluated efficacy of mechanical scarification (dozer blade, disk trencher, clearing rake, and whole tree skidding) and herbicide to control bluejoint grass, a major competitor of tree seedlings. Simulating successional trajectory over 5-80 years illustrated positive correlations of stem density and years since logging for aspen, birch, and willow, with average stem density peaking at 10-15 years post-logging (Fig. 1). Density of 4800 stems/acre (12,000/ha) represented good stocking after logging and ground scarification. Twenty management recommendations are provided to enhance early successional moose habitat in hardwood and mixed spruce-hardwood stands in Alaska. “These guidelines mutually benefit reforestation through enhanced hardwood regeneration and lessened the probability that individual hardwoods will be damaged or stunted by browsing” (p. 368).

◆ **Collins, W.B., D. Williams, and T. Trapp. 2001b.** Spruce beetle effects on wildlife, 1 July 1997-30 June 2001. Alaska Department of Fish and Game. Federal Aid in Wildlife Restoration, research final performance report, grants W-27-1 through W-27-4, study 1.53, Juneau, Alaska. http://www.adfg.alaska.gov/static/home/library/pdfs/wildlife/research_pdfs/f01hab_beetlef.pdf

Author summary: A total of 594 point counts of breeding birds were conducted in Kenai lowland forests during the 1998 season, using the variable circular plot method. Townsend’s Warbler (*Dendroica townsendi*) and Golden-crowned Kinglet (*Regulus satrapa*) may be most negatively affected by habitat changes caused by bark beetles (*Dendroctonus rufipennis*). Further, these two species are essentially absent from salvage-logged areas, and Townsend’s Warblers are rare in mixed birch (*Betula papyrifera) -spruce* (*Picea glauca*) forest. Three-toed Woodpeckers (*Picoides tridactylus*) benefit from bark beetle infestation but decline when the infestation subsides and availability of beetle larvae decreases. Solitary Sandpipers (*Tringa solitaria*), an easily overlooked species, may be affected by spruce mortality and logging. Species diversity in selectively logged stands is maintained in direct proportion to remaining tree densities, with a shift toward species preferring open habitats. Selectively logged mixed birch-spruce forests maintained higher bird diversity than logged spruce stands because of greater tree density and vegetative diversity. We completed a literature review of northern owl survey and census methods and an owl survey protocol, with accompanying amphibian survey protocol, for standardization of Alaska owl surveys.

Eighty-nine percent of small mammals trapped in Kenai lowland forests were Northern red- backed voles (*Clethrionomys rutilus*). Red-backed vole populations were highest in pure spruce stands infested with bark beetles, but lowest where beetle-killed stands had been salvage logged. In either pure spruce or mixed hardwood-spruce stands, logging produced dense stands of bluejoint grass (*Calamagrostis canadensis*) and reduced abundance of many shrub and herbaceous understory species. Overall, relative abundance and numbers of reproducing female red-backed voles were positively correlated with berry abundance and moss cover but negatively correlated to bluejoint grass cover. However, neither beetle infestation nor logging significantly impacted red-backed vole populations in mixed hardwood-white spruce habitat, presumably because the hardwood component of the overstory was retained and much less understory was directly affected. During 2000, a thesis detailing the small mammal portion of this study was completed. Regeneration of browse by paper birch and willows was relatively poor, probably due to lack of scarification. Combined with insufficient sampling methods, failed or extremely poor berry crops in all sites masked any potential differences in berry productivity.

Notes: Sampling occurred in upland and lowland stands >100 years old in spruce and mixed forest that were disturbed during the 3-5 years prior to the 1st year of study stands. Disturbance types were salvage logging without scarification and beetle infestation to an extent that reduced canopy cover. Stands without evident human disturbance or fire in the last 100 years were sampled as non-treated controls.

◆ **Cox, W.T. 1938.** Snowshoe hare useful in thinning forest stands. Journal of Forestry 36:1107-1109.

Notes: This brief report from northwestern Minnesota describes that hares are "highly beneficial in thinning thickets of pine, spruce, aspen, and other species…" (p. 1107). Jack pine plots showed seedlings reductions of 85-99% from an average starting density of 30,690 stems/acre to an average thinned density of 2195 stems/acre. Hares were observed to thin dense stands of seedlings 0.5-2.0 feet tall until the stand was so open the author perceived the hares were fearful of avian predators due to lack of cover. As crowns of remaining trees fill out, hares may again find adequate cover for a second round of thinning. If hares are not present, dense stands would remain "unproductive" for 10-25 years until self-thinning competition occurred, during which time risk of fire or insect damage is incurred in dense stands. Hares were perceived to effect pre-commercial thinning at a cost saving. Presence of beavers was noted as serving a similar purpose near water bodies, in addition to dam impoundments providing a water supply for fire suppression. The author noted a recommendation in a bulletin

“Reforestation on the National Forests” promoting the practice of “planting or seeding in the center of large recent burns or other openings rather than near the edge of forests because of greater immunity from damage by rodents” (p. 1109). This practice also promotes “uneven stands” rather than continuous cover [potential benefit of discontinuous fuels in areas where fire is prevalent]. The author also noted the advisability of planting at lower stocking rate so tree cover does not become attractive to hares and the height growth and “coarse bark” of faster growing trees at lower stocking made the trees more “immune to hare damage.” [It is assumed “reforestation” in this example is conifer.]

◆ **Danell, K., L. Edenius, and P. Lundberg. 1991.** Herbivory and tree stand composition: Moose patch use in winter. Ecology 72:1350-1357.

Author abstract: Foraging decisions by large herbivores in a heterogenous environment with several available plant species are a scale problem. If, for example, the foraging decisions primarily occur at the stand level, then stands of trees might be regarded as patches within a habitat of several stands over which intake rate is to be maximized. The food consumption within a stand should be in proportion to the availability of different food types. If, on the other hand, food selection occurs at the tree level within a stand, then the individual trees are regarded as "patches"; total stand exploitation should then be the result of foraging decisions made within the stand. We tested these two hypotheses in field experiments in winter with free-ranging moose (*Alces alces*) having access to artificial stands of trees. In these stands Scots pine (*Pinus sylvestris*) was mixed with either aspen (*Populus tremula*) or alder (*Alnus incana*). In experiment A, where the total available pine biomass per stand was much greater than any of the additional species, total stand consumption did not differ between stand types. In experiment B, where pine biomass did not dominate to the same extent, pine+aspen stands were more heavily used than pine+pine and pine+ alder stands. The within-stand consumption of different species appeared to be nonrandom, i.e., the tree biomass was not consumed in proportion to availability. The mean pine biomass consumption per tree did not differ between stand types in either experiment. We conclude that the food selection appears to occur primarily at the tree level within stands. The level of decision might also be important for the performance of the plant species exploited. The results from this study question the general validity of recent hypotheses regarding "associational protection" in plant communities. We suggest that the optimal patch use approach taken in this study might give better insight in these kinds of plant-animal inter-action problems.

Key words: associational plant refuge hypothesis; biomass composition; browsing; food-plant selection; herbivory; moose; optimal foraging; patch use; species composition; stand vs. individual plant level; tree stand.

<u>Notes</u>: Density during experiments was 2.0-2.6 moose/mi^2

◆ **Danell, K., T. Willebrand, and L. Baskin. 1998.** Mammalian herbivores in the boreal forests: their numerical fluctuations and use by man. Conservation Ecology (online), Volume 2, Issue 2, Article 9 http://www.ecologyandsociety.org/vol2/iss2/art9/

Author abstract: Within the boreal zone, there are about 50 native mammalian herbivore species that belong to the orders Artiodactyla, Rodentia, and Lagomorpha. Of these species, 31 occur in the Nearctic and 24 in the Palaearctic. Only six species occur in both regions. Species of the family Cervidae have probably been, and still are, the most important group for man, as they provide both meat and hides. Pelts from squirrels, muskrats, and hares were commercially harvested at the beginning of the century, but have less value today. The semi-domestic reindeer in the Palaearctic produces meat and hides on a commercial basis. It is also used for milking, to a limited extent, as is the semi-domestic moose in Russia. The Siberian musk deer is used for its musk and is raised in captivity in China. All species heavier than 1 kg are utilized by man, those with a body mass in the range 1 kg - 1 hg are sometimes used, and species lighter than 1 hg are rarely used. Here, we review the numerical fluctuations in terms of periodicity and amplitude, based on an extensive data set found in the literature, especially from the former Soviet Union. Current understanding of the underlying factors behind the population fluctuations is briefly reviewed. Management and conservation aspects of the mammalian herbivores in the boreal zone are also discussed. We conclude that there is a challenge to manage the forests for the mammalian herbivores, but there is also a challenge to manage the populations of mammalian herbivores for the forests.

Notes: This characterization of relative use by humans based on size of mammal highlights the challenge of using harvest by the public (no cost to forest manager) to control abundance of smaller mammals that may cause reduced stocking, reduced growth, or damage to trees.

◆ **Darris, D. 2005.** Plant fact sheet for bluejoint (*Calamagrostis canadensis*). USDA-Natural Resources Conservation Service, Plant Materials Center, Corvallis, OR. 2pp.

Compiler abstract. This fact sheet summarizes uses, status, and characteristics. The author describes how the species gets established, and methods for control where it becomes weedy or invasive.

◆ **Edenius, L., Bergman, M., Ericsson, G. & Danell, K. 2002.** The role of moose as a disturbance
factor in managed boreal forests. Silva Fennica 36(1): 57–67.

Author abstract: We review the interactions between moose (*Alces alces*) and native tree species in Fennoscandia. The Fennoscandian boreal forests have been intensively managed for wood production over decades. Moose population density is also relatively high in these northern forests. Forest management affects habitat characteristics and food resources from regeneration to final harvest, with the most significant effects occurring early in the stand development. The plant-animal interactions found in such a situation may be different from what has been observed in natural boreal forests with low densities of moose (e.g. in North America). The strong focus on Scots pine (*Pinus sylvestris*) in forest regeneration in conjunction with a homogenisation of the landscape structure by clearcutting has favoured moose. Forest development is controlled by man from regeneration to final harvest, and in relation to human-induced disturbances the disturbance by moose is relatively small, but occurs on different spatial levels. At the landscape level, the most prominent effects of moose seem to be suppression and/or redistribution of preferred browse species. At the forest stand level moose primarily induce spatial heterogeneity by browsing patchily and exploiting existing gaps. At the tree level, moose damage trees and lower timber quality, but also create substrate types (e.g. dead and dying wood) valuable for many organisms. Co-management of moose and forest requires good monitoring programmes for both plants and animals, as well as extensive ecological knowledge on the relations between moose and their food plants on different spatial levels.

Notes: Fennoscandian forests are substantially different from natural forests of North America in many structural characteristics, and moose densities are typically higher in Fennoscandia [in part from more younger forest that provides forage and in part because large predators are rare or absent]. "First, we review the typical silvicultural practices and describe how they affect habitat conditions and food resources for large ungulates at the stand level. Second, we address effects of forest management on habitat suitability, carrying capacity, and patterns of plant utilization at the landscape scale. Third, we highlight impacts by moose in a dynamic perspective by discussing their role as disturbers. Finally, we discuss some emergent issues from monitoring and management perspectives" (p. 58). Much of the review focused on moose interactions with pine ecology and silvicultural practices, noting differences from North American studies where moose occur at lower density, habitat quality is more variable (less managed forest), and scale of disturbance is of coarser grain (large fires).

◆ **Fayt, P. 2004.** Old-growth Boreal Forests, Three-toed Woodpeckers and Saproxylic Beetles: The Importance of Landscape Management History on Local Consumer-Resource Dynamics. Ecological Bulletins 51:249-258.

Author Abstract: I investigated if the distribution of insect prey influencing the breeding success and being the winter diet of three-toed woodpeckers Picoides tridactylus changed with edge proximity in old growth forest patches, and if edge effects depended upon the management history of the surrounding matrix. Measurements of three-toed woodpecker habitat quality during two years included the number of bark beetle species, a variable positively associated with the woodpecker brood size, the relative abundance of wood-boring beetles, whose larva account for the bulk of nestlings' diet, and the relative abundance of bark beetles overwintering on standing spruces, its winter food. Of eight woodpecker habitat patches, five were surrounded by ditched clear-cuts and three were surrounded by untouched peatlands. Insects were sampled yearly with window-flight traps located at various distances from the nearest edge. Of 17169 beetles collected, 12843 were bark beetles (Coleoptera, Scolytidae). Contrasting patterns in woodpecker prey distribution were found in natural vs managed boreal forest landscapes. In habitat patches with natural edges and unditched surrounding, number of bark beetle species did not change and abundance of bark beetles living on standing spruce decreased from the edge. Looking at the species composition of bark beetle communities living preferentially on logs, roots, stumps, and standing trees, only the species assemblage of the standing trees showed responses to edge proximity, becoming richer with increasing distance from the edge in stands with managed surrounding. Results on prey distribution suggest the importance of old-growth swamp forests in the boreal landscape to lower the threshold in the proportion of original habitats that is required to ensure the reproduction and secure the winter food supply of a viable three-toed wood-pecker population.

◆ **Fayt, P., M. M. Machmer, and C. Steeger. 2005.** Regulation of spruce bark beetles by woodpeckers--a literature review. Forest Ecology and Management 206:1-14 [M]
Author abstract. Relative to host suitability and invertebrate predators and parasitoids, predation by vertebrates generally has been assigned a trivial role in the dynamics of conifer bark

beetle populations (Coleoptera, Scolytidae). Here, we present the results of a literature review of quantitative studies that address the trophic relationship between bark beetles infesting spruce (*Picea* spp.) and woodpeckers. Evidence from empirical observations, exclosure experiments and modelling suggests that predatory woodpeckers, and especially three-toed woodpeckers (*Picoides tridactylus*), may play a significant role in regulating bark beetle populations in coniferous forest landscapes. A general mechanistic framework is proposed to account for variation in the predatory impact of woodpeckers on the bark beetle community living on spruce, based on available information. It emphasizes interrelations between the multi-scale heterogeneity of forest habitat as driven by succession and disturbance patterns in space and time, predator–prey population processes operating at landscape levels and local consumer–resource dynamics. In particular, the response of woodpeckers to local beetle epidemics depends on how the structural and spatial properties of the surrounding patches influence reproduction, determine abundance and facilitate predator dispersal. Despite a paucity of landscape-level data, circumstantial evidence documents a stabilising role of woodpeckers on the population dynamics of their
prey.

◆ **Flower, C.E., L.C. Long, K.S. Knight, J. Rebbeck, J.S. Brown, M.A. Gonzales-Meler, and C.J. Whelan. 2014.** Native bark-foraging birds preferentially forage in infected ash (*Fraxinus spp.*) and prove effective predators of the invasive emerald ash borer (*Agreilus planipennis* Fairmaire). Forest Ecology and Management 313:300-306. [L]

Author abstract. Inadvertently introduced into North America in the 1990s, the invasive emerald ash borer (EAB, *Agrilus planipennis*) has been spreading across the Great Lakes Region resulting in widespread ash tree (*Fraxinus* spp.) mortality. Native woodpeckers and other bark-foraging insectivores represent one of the few potential natural predators of EAB in the U.S. In this study, we combined observational and destructive tree harvesting approaches to assess bark-foraging bird predation on EAB larvae in a deciduous forest of central Ohio. Results of our observational study show that in an EAB impacted forest, bark-foraging birds forage more heavily on ash trees than non-ash trees, and that they forage preferentially on ash trees that exhibit canopy decline symptoms relative those with healthy canopies. These patterns were further supported by the destructive sampling of 46 ash trees wherein predation by bark-foragers significantly reduced tree-level EAB densities by upwards of 85%. Bark-foraging predation intensity increased with increased EAB infestation levels, with bark-foragers harvesting ~45% of EAB in trees with thinning canopies compared to ~22% in ash trees with healthy canopies. Woodpeckers harvest EAB in a density-dependent pattern that could contribute to population control. Despite bark-forager predation, EAB had a high likelihood of successfully emerging from the heavily infested ash trees (~30% or 35 EAB per m^2). Our results suggest that woodpeckers and other bark-foragers may use visual canopy decline, and perhaps other cues, to target ash trees with increased EAB densities. Moreover, our results provide insight into the indirect effects of invasive species on biotic interactions in forest ecosystems highlighting potential shifts in bark-foraging and other bird behaviors in response to a novel forest pest. Bark-foragers respond to EAB infestation and may thus potentially help regulate EAB populations and their spread in a mixed deciduous forest. We suggest that maintaining snags and nesting sites during and after forest pest outbreaks may enhance populations of bark-foraging bird species and, thus, their biological control of pest insects in temperate deciduous forests.

◆ **Fuller, A.K., D.J. Harrison and H.J. Lachowski. 2004**. Stand scale effects of partial harvesting and clearcutting on small mammals and forest structure. Forest Ecology and Management 191: 373–386. [L]

Author abstract. Documenting responses of small mammals to alternative forestry practices (e.g., clearcutting versus partial harvesting versus no management) facilitates inferences about effects on wildlife communities. We compared abundances of small mammals (voles, mice, and shrews) during four summers among partially harvested mixed coniferous–deciduous stands (52–59% basal area removal, 15 m2/ha live-tree residual basal area), regenerating commercial clearcuts (11–20-year-old), mature (>12 m tree height) mixed stands, mature deciduous, and mature coniferous stands. Partially harvested stands had significantly greater overall abundance of deer mice (*Peromyscus maniculatus*) than mature mixed stands, but abundances of red-backed voles
(*Clethrionomys gapperi*) and short-tailed shrews (*Blarina brevicauda*) were not significantly different. Regenerating clearcut stands had significantly lower abundances of voles and mice relative to mature mixed stands, and ranked low in abundance of shrews. Mature coniferous stands also ranked low in relative abundance of shrews and had the lowest abundance of deer mice relative to other mature stand types. Mature deciduous stands ranked high in abundance of deer mice and had the greatest abundance of short-tailed shrews among all stand types. Despite reduced canopy closure, lower relative density of coniferous trees and saplings, and decreased basal area of deciduous trees and snags, partially harvested stands supported densities of mice and voles comparable to mature mixed-forest types. Forest harvesting practices that retain some structural attributes of mature forests may be beneficial to small mammals and associated predators that utilize mice, voles, and shrews as prey.

Notes. This study indicates that "forestry harvesting practices that retain structural attributes of mature forests may be beneficial to small mammals and associated predators." This is germane to the idea of retaining late seral features and snags will be beneficial both in terms of maintaining small mammals that distribute fungal spores associated with roots of tress, but also maintaining predators that can reducing small mammal herbivory.

◆ **Giffard, B., L. Barbaro, H. Jactel, and E. Corcket. 2013.** Plant neighbours mediate bird predation effects on arthropod abundance and herbivory. Ecological Entomology 38:448-455. [L]

Author abstract. 1. Tritrophic interactions among plants, herbivores and predators are expected to be influenced by the surrounding vegetation. Neighbouring plants can influence focal plant colonisation by herbivorous insects and the foraging behavior of natural enemies, such as insectivorous birds.

2. The aim of the experiment was to disentangle the interactive effects of neighbouring plants and avian predation on arthropod abundance and insect leaf damage in oak tree seedlings, using exclusion cages and vegetation removal.

3. The presence or removal of surrounding herbaceous vegetation differentially mediated top-down effects of insectivorous birds on distinct arthropod guilds and herbivore damage in seedlings. Avian predation reduced sawfly larval abundance regardless of the presence of plant neighbours, lepidopteran larval abundance only when plant neighbours were removed, and spider

abundance only when plant neighbours were left intact. The removal of plant neighbours increased prey accessibility for foraging insectivorous birds and decreased chewer damage on seedlings. The density of concealed-feeder insects (leaf miners) increased with plant neighbour removal and when seedlings were less damaged by chewer guild, suggesting intraguild competition.

4. These results highlight the strong indirect effects of neighbouring vegetation on tritrophic interactions involving a focal plant species, its associated herbivores and the upper trophic level of predators.

Notes. Presence or removal of neighboring vegetation can affect whether insects occur on a given focal plant species. Avian predation, however, did not vary relative to whether neighboring vegetation was present or absent.

◆ **Gill, R.M.A. 1992a.** A review of damage by mammals in north temperate forests: 2. Small mammals. Forestry 65:281-308.

Author Summary: The causes of bark stripping and browsing by squirrels, rabbits, hares, voles and edible dormice in forests and woodlands are reviewed. Population density and tree characteristics are the most significant causes of damage, but habitat characteristics, particularly where they contribute to higher densities, are also important. There are still aspects of some forms of damage which are not well understood. Agonistic behaviour is thought to be as or more important than feeding in contributing to grey squirrel damage, but the difficulties of making observations in the wild have made it impossible to verify the role of behaviour. Improvements in understanding of all forms of damage could come from more investigations on tree quality (including the role of phenols, terpenes and other nutritional components) and the relationships between habitat variables and damage. Methods of predicting the risk of damage are discussed.

Notes: This review focused on damage problems in Britain but drew heavily on studies carried out in other northern temperate ecosystems. No attempt was made to discuss the merits of various control measures, nor the influence of seed predators on regeneration, which could be beneficial by reducing initial stocking density. Small herbivore damage can be more difficult to mitigate than larger herbivore damage because shooting and fencing is impractical and population abundance can recovery rapidly from control measures (e.g., poison). The paper reviewed characteristics of each type of damage and the relationship of damage to the population and nutritional ecology of the animal concerned to identify research needs and prospects for improved methods of damage prevention.

Extent of bark stripping from the upper portions of the trunk or branches by squirrels is often positively correlated to squirrel density. Squirrel abundance is in turn tied to seed abundance, which can increase reproductive success and overwinter survival. Red squirrels in interior AK can consume white spruce buds during cone failures (M.C. Smith 1968, Journal of Wildlife Management 32:305-317) and girdle Alaska birch after heavy cone crops (H.J. Lutz 1956, Journal of Forestry 54:31-33). [*Whether these observations are population level effects would need to be examined in primary literature sources*.] Vole damage is primarily bark stripping at ground level that in complete coverage becomes girdling, but root damage can also occur [*determine for AK whether girdling and root damage more likely for conifers than deciduous*]. Vole damage is widely reported to coincide with periods of vole abundance, and damage seems to be most severe where populations are in peak cyclic years because food quantity or quality is depleted. Vole density is positively correlated with vegetation cover; thus, habitat alterations that affect vole populations also influence damage levels. Damage in Scandinavia is more severe on former pastures where grazing has ceased than on clearcuts, which presumably have lesser grass cover [*experience with* Calamagrostis *in AK?*]. Rabbits usually browse progressively away from cover, thus damage is patchy and most severe near cover. [European] hares have a habit of browsing down rows of planted trees.

Conclusions were that damage is often positive correlated to density in small mammals, so recognizing the role of predators in controlling small mammal abundance should enhance efforts for predator conservation in managed forests.

◆ **Gill, R.M.A. 1992b.** A review of damage by mammals in north temperate forests: 3. Impact on trees and forests. Forestry 65:363-388.

Author Summary: The impact of mammals on trees and forest crops is examined by reviewing the scientific literature. The degree of growth loss, stem deformation and the likelihood of death from browsing all increase with the severity of damage. The effect of the damage depends very much on the tree species, age and season. Many studies reveal that some compensatory growth occurs after browsing, but there is a serious lack of long-term data and more work that links the incidence of damage to ultimate yield loss is required. Browsing can also make trees more or less palatable and this could have a marked effect on the likelihood of recovery, but this subject requires further research for trees growing in British conditions. Bark stripping results in timber staining and decay but does not appear to cause serious growth loss. The amount of stem decay usually increases with wound size and tree vigour but a considerable amount of residual variation remains to be explained. The success of natural regeneration depends on both herbivore and seedling density. Changes in tree species composition reflect the palatability of seedlings as well as their ability to recover. Browsing by deer usually causes a decrease in shrub and herbaceous plant biomass in the ground vegetation and an increase in grasses, ferns and mosses.

<u>Notes</u>: Author partitioned review of primarily large mammal herbivory into effects on individual trees (e.g., growth delay) and effects on forest composition and understory vegetation. Trees are most affected by the type or timing of browsing that most severely depletes nutrient or carbohydrate reserves. Winter damage is relatively more severe for conifers that do not lose needles than for deciduous trees. Leaves and needles contain higher concentrations of nitrogen during periods of active growth. Leader length seems to be affected more by browsing than does girth increment. Browsing creates an imbalance in the shoot to root ratio that can be corrected by altering allocation of photosynthetic products and nutrients to the shoots at the expense of the roots. Thus, compensatory growth can occur to an extent. Browsing can reduce palatability and digestibility of deciduous trees by causing production of secondary metabolites in new juvenile twigs, inhibiting further browsing (opposite effect in Scot's pine, which becomes more palatable). Studies show mixed results for effects of bark stripping on radial growth; it may occur primarily below the wound but may be temporary, decreasing rapidly 2 or more years after damage. Bark stripping can predispose trees to stem deformation or breakage and the

development of rot or stain. Fertilization can reduce concentration of secondary metabolites and increase palatability in *Betula* spp.

There are few examples of financial cost assessments of browsing damage to timber production and no examples [as of 1992] for documented growth delay or deformation >22 years after damage occurred. Effect of bark stripping on defect is easier to document because it occurs later in rotation. In all instances there is likely to be considerable variability among stands in response to damage. Modeling is possible but requires information on growth rates after damage, which can be rapid.

◆ **Hansson, L. 1986.** Bark consumption of voles in relation to snow cover, population density and grazing impact. Ecography 9:312–316.

Author abstract. The voles *Microtus agrestis* and *Clethrionomys glareolus* consume more bark in north than in south Sweden in spite of lower availability in the former area due to snow-pressed ground. Field experiments with genetically homogeneous aspen sticks demonstrated that this pattern reflects differences in animal behaviour and not differences in plant palatability. Within a region consumption in snow-pressed areas was usually less than in subnivean spaces or runways. The amount of bark consumption was generally correlated with population density and amount of grazing impact. Great differences in bark consumption between north Swedish areas with high peak vole populations and south-central Swedish areas with moderate peak numbers imply that nutrition is of different importance at population declines in different regions. The ability of voles to move into snow-pressed areas and locate woody sticks in the snow suggests that control of ground cover will not protect tree seedlings at reforestation.

◆ **Hansson, L. and T. Larsson. 1978.** Vole diet on experimentally managed reforestation areas in northern Sweden. Holarctic Ecology 1:16-26. [M]

Author abstract. In northern Sweden two field experiments with the reforestation techniques soil scarification, ploughing, burning and grass herbicidal treatment were performed. Small rodents were trapped regularly on the managed plots and their stomachs were examined microscopically for diet composition. Both bank voles *Clethrionomys glareolus* and field voles *Microtus agrestis* were common on the reforestation areas while only a small number of grey-sided voles *Clethrionomys rufocanus* were taken. All three species underwent a population cycle during the studies. The management techniques generally resulted in small and irregular effects on the food selection. The most pronounced changes were lower intake of grasses by *M. agrestis* after herbicidal treatment and of filamentous tree lichens by *C. glareolus* after most treatments. Both bank voles and field voles ate predominantly forbs in the summer half of the year, whereas the field voles took also a considerable amount of grass. As a complement to green vegetable-matter bank voles ate berries and fungi in summer-autumn and tree lichens at other times of the year, but seeds and animals food only in very small amounts. All three species consumed large quantities of dwarf-shrubs in autumn and especially in winter. Considerable amounts of bark were eaten by field voles and a smaller proportion by bank voles in autumn-winter. Both for bank and field voles there were indications of worsening food conditions as the population cycle went on. There were, for example, an increase in grass and bark intake in field voles and a decrease in seeds and berries for the bank vole.

Notes. “Scarification” was 2000 patches per hectare (30 cm x 30 cm) created with tractor-drawn implements, which overall caused little disturbance on the forest floor. Small mammals were snap-trapped during 1972-75. Abundance of *Microtus agrestis* peaked in 1973 -74, and its consumption of bark increased across all management treatments from 1972-74. The authors noted that “the influence of habitat heterogeneity [on associated tree damage] has still to be examined” (p. 25). There was substantial variation in vole species abundance between the 2 study sites and several changes in diet over time among species, possibly in response to detrimental changes in diet quality as vole abundance declined.

◆ **Hewitt, R.E., E. Bent, T.N. Hollingsworth, F.S. Chapin, and D. L. Taylor. 2013.** Resilience of Arctic mycorrhizal fungal communities after wildfire facilitated by resprouting shrubs. Ecoscience 20: 296-310.

Author abstract. Climate-induced changes in the tundra fire regime are expected to alter shrub abundance and distribution across the Arctic. However, little is known about how fire may indirectly impact shrub performance by altering mycorrhizal symbionts. We used molecular tools, including ARISA and fungal ITS sequencing, to characterize the mycorrhizal communities on resprouting *Betula nana* shrubs across a fire-severity gradient after the largest tundra fire recorded in the Alaskan Arctic (July-October 2007). Fire effects on the components of fungal composition were dependant on the scale of taxonomic resolution. Variation in fungal community composition was correlated with fire severity. Fungal richness and relative abundance of dominant taxa declined with increased fire severity. Yet, in contrast to temperate and boreal regions with frequent wildfires, mycorrhizal fungi on resprouting shrubs in tundra were not strongly differentiated into fire-specialists and fire-sensitive fungi. Instead, dominant fungi, including taxa characteristic of late successional stages, were present regardless of fire severity. It is likely that the resprouting life history strategy of tundra shrubs confers resilience of dominant mycorrhizal fungi to fire disturbance by maintaining an inoculum source on the landscape after fire. Based on these results, we suggest that resprouting shrubs may facilitate post-fire vegetation regeneration and potentially the expansion of trees and shrubs under predicted scenarios of increased warming and fire disturbance in Arctic tundra.

Notes: Although this paper deals with recovery post-fire, it emphasizes the importance of a source point that provides tree roots with a soil-based “inoculum” of fungal spores, which are critical to tree establishment and growth. Other papers we cite in this bibliography suggest that small mammals (particularly red-backed voles) are important dispersers of fungal spores, and hence provide tree roots with a source of this very important fungal “inoculum”.

◆ **Hodges, K.E. 1999.** The ecology of snowshoe hares in northern boreal forests. Pages 117-162 *in* L.F. Ruggiero, K.B. Aubry, S.W. Buskirk, G.M. Koehler, C.J. Krebs, K.S. McKelvey, and J.R. Squires, editors. Ecology and Conservation of Lynx in the United States. U.S. Forest Service, General Technical Report RMRS-GTR-30WWW, Fort Collins, Colorado. [M]

Author abstract. Snowshoe hares exhibit eight to 11 year population fluctuations across boreal North America, typically with an amplitude of 10 to 25 fold. These fluctuations are synchronous across the continent, with the most recent peak densities occurring in 1990 and 1991. The numeric cycle is driven by changes in survival and reproduction, with annual survival of adults ranging from approximately five to 30% and annual natality ranging from approximately six to 20 leverets/female. These parameters show cyclic changes because of functional and numerical responses of predators and changes in food supply. Predator densities show approximately two to 10 fold fluctuations during the hare cycle. The cyclicity of hares may be partly explained by regular behavioral shifts, with repercussions on their physiology, availability to predators, reproduction, and survival. However, this hypothesis needs more empirical support before it can be accepted.

◆ **Holling, C.S. 1959.** The components of predation as revealed by a study of small-mammal predation of the European sawfly. Canadian Entomologist 91:293-320. [L]

Author abstract. The fluctuation of an animal's numbers between restricted limits is determined by a balance between that animal's capacity to increase and the environmenta1 checks to this increase. Many authors have indulged in the calculating the progressive increase of a population when no checks [were] operating. Thus Huxley calculated that the progeny of a single *Aphis* in the course of 10 generations, supposing all survived, would "contain more ponderable substance than five hundred millions of stout men; that is, more than the whole population of China", (in Thompson, 1929). Checks, however, do occur and it has been the subject of much controversy to determine how these checks operate. Certain general principles—the density-dependence concept of Smith (1955) , the competition theory of Nicholson (1933)—have been proposed both verbally and mathematically, but because they have been based in part upon untested and restrictive assumptions they have been severelv criticized (e.g. Andrewartha and Birch 1954). These problems could be considerably clarified if we knew the mode of operation of each process that affects numbers, if we knew its basic and subsidiary components. predation, one such process, forms the subject of the present paper.

Notes. This classic ecological case study describes predation by two species of shrews (insectivores: masked shrew, *Sorex cinereus* and short-tailed shrew, *Blarina brevicauda)* and the deer mouse (granivore: *Peromyscus maniculatus)* on cocooned European pine sawflies (*Neodiprion sertifer*) in a plantation of Scots pine (*Pinus sylvestris*) and jack pine (*P. banksiana*) in southwestern Ontario. The summary and conclusions (p. 318) are partly paraphrased for brevity as follows: The functional response describes an increase in the number of prey consumed per predator as prey density rises, whereas the numerical response describes change in the density of predators as a result of increase in prey density. The mammals each showed a functional response of a sigmoidal increase to a constant maximum consumption, but the rate of increase of consumption differed among species. The increase in density of predators resulted from increased breeding. Because the reproductive rate of small mammals is so high, there was an almost immediate increase in density with increase in food. The two basic components of predation (functional and numerical responses) can be affected by a number of subsidiary components: prey characteristics, density and quality of alternate foods, and characteristics of the predators. It was shown experimentally that these components affected the amount of predation by lowering or raising the functional and numerical responses. Decrease of the strength of stimulus from prey, one prey characteristic, lowered both the functional and numerical responses. Alternatively, the quality of alternate foods affected the two responses differently. Increase in the palatability or in the number of kinds of alternate foods lowered the functional response but promoted a more pronounced numerical response. The peaked type of predation shown by small mammals can theoretically regulate the numbers of its prey if predation is high enough to match the effective reproduction by prey at some prey density. Even if this condition does not hold, however, oscillations of prey numbers are damped. Since the functional and numerical responses undoubtedly differ for different species of predator, predation by each is likely to peak at a different prey density. Hence, when a large number of different species of predators are present the declining phase of predation is displaced to a higher prey density so that the prey have less change to "escape" the regulation exerted by predators. The scheme of predation presented here is sufficient to explain all types of predation as well as insect parasitism. It permits us to postulate four major types of predation differing in the characteristics of their basic and subsidiary components.

◆ **Hörnberg, S. 2001a.** Changes in population density of moose (*Alces alces*) and damage to forests in Sweden. Forest Ecology and Management 149:141-151

Author abstract: The moose population in Sweden has undergone large changes during the last decades. This fact has caused concern for both the forestry and hunters. In this study the interactions between the moose population and forest vegetation were investigated. The information on moose population density was collected using questionnaires sent to the managers of county hunting boards in 1987, 1990, and 1992. Data concerning harvesting of moose by hunting were taken from the Swedish National Environment Protection Agency (official statistics), and the data used to analyse forest damage and browsing pressure caused by moose were from the Swedish National Forest Inventory (NFI). The study showed that the moose population increased in Sweden until the winter 1981-1982, when the population was estimated to be 314,000. This corresponds to an average density of approximately 1.1 moose/km^2 productive forest land. However, the differences in moose density among counties were large and probably connected to local management strategies and biological conditions. After 1982, the moose population was reduced in many areas, and in 1992 the moose population was estimated to be 225,000. The reduction was caused, to a major part, by increased harvest. There was a significant correlation between reported population changes and registration by the NFI of browsing on preferred tree species and damage in young pine stands. This indicated that the county board advisers had correctly detected population trends and that it is possible to detect changes in a moose population by using a combination of objective browsing and damage inventories. It was, nevertheless, impossible to determine any significant correlation between moose density and damage level. The damaged area of young pine stands per moose varied among counties. Differences in climate, forage coverage, habitat patterns, period of growth etc. were considered to be the main reasons for the variation. There was a significant correlation between the proportion of young pine stands (percent of the total area young forest) and damaged hectares of young pine stands per moose, which shows that the browsing utilisation of pine is closely connected to the available proportion of pine in the total forage bag.

Notes: Species evaluated in 10m radius plots were pine (*Pinus silvestris, Pinus contorta*), birch (*Betula pendula, Betula pubescens*), and a group called other forage: aspen (*Populus tremula*), rowan (*Sorbus aucuparia*), sallow/willow (*Salix* spp.), juniper (*Juniperus communis*), oak (*Quercus robur*), and ash (*Fraxinus excelsior*). "Browsing pressure" in the NFI is the proportion class (none 0-10%, 11-33%, 34-66%, and 67-100%) of only the prior year growth that had been browsed. "Moose damage" to vegetation in the NFI is the proportion of severely damaged main stems for stands with pine <7 m tall. The author cites other studies from Scandinavia showing snow depth positively correlated to browsing damage

◆ **Hörnberg, S. 2001b.** The relationship between moose (*Alces alces*) browsing utilisation and the occurrence of different forage species in Sweden. Forest Ecology and Management 149:91-102

Author abstract: The occurrence of forage in Swedish forests and its consumption by moose at the bush and tree levels have been mapped with the help of data from the Swedish National Forest Inventory (NFI) 1969-1972 and 1983-1987. The correlation between forage occurrence and consumption has also been investigated. In total, some 120 000 sample plots form the basis of the study. Birch was by far the most common source of forage in forests and other land-use classes. The occurrence of forage species varied between regions and most of the forage occurred in low coverage classes, making forage consumption largely dependent on the presence of forage. Most of the browsing vegetation (91%) consisted of six species: birch, sallow/willow, pine, juniper, rowan, and aspen in order of foraging preference. Willow and birch were at the top of the consumption list in most regions, whereas the consumption of pine varied from region to region. Regression analysis showed that there was a significant correlation between the consumption of the six most preferred species and the proportion of available forage per species. It has also been established that the proportion of other forage affected the consumption of pine and birch. The most significant correlation, however, was between the occurrence of pine feed and the consumption of pine. No connection could be found between the occurrence of birch feed and the consumption of pine. Consumption was proportional to the share of forage in each coverage class and between the share of forage in forests and other land-use classes. Willow and rowan were among the most utilised forage, at an average of 21 and 19%, respectively.

Notes: Forage utilization is a mean proportional number of live twigs browsed among all species divided by the proportional canopy cover among all species, for the area above snow and within the 2.5-3.0 m height range accessible to moose in winter.

◆ **Huitu, O. M. Rousi, and H. Henttonen. 2013**. Integration of vole management in boreal silvicultural practices. Pest Management Science 69:355–361. [M]

Author abstract. Voles of the genera *Microtus* and *Myodes* are widespread and among the most abundant of small mammal species in the boreal zone of the Northern Hemisphere. They are keystone herbivore species in northern ecosystems, and they have profound impacts on both higher and lower trophic levels. Voles are also major silvicultural pests, damaging millions of tree seedlings in years of peak abundance. Prevention of vole damage to silviculture has proven to be very difficult owing to the ubiquity of both suitable vole habitat and potential damage sites across landscapes. The degree of damage inflicted by voles on seedling stands is largely, but not solely, determined by prevailing vole densities, which often fluctuate in 3–4 year population cycles. Silvicultural practices related to site habitat manipulation and/or choice and rearing of seedling material may also greatly influence the severity of vole damage to seedlings. The manipulation of these practices is currently at the forefront of methods potentially applicable to control vole damage in boreal forests. This paper reviews current evidence for the efficacy and present recommendations for further development and application of these methods to mitigate vole damage to seedling stands in boreal silviculture. [*Myodes* is a taxonomic revision of *Clethrionomys*]

◆**Jacobs, K.M., and D.L. Luoma. 2008.** Small mammal mycophagy response to variations in green-tree retention. Journal of Wildlife Management 72:1747–1755. [M]

Author abstract. We studied the effects of 6 green-tree retention levels and patterns on the diets of northern flying squirrels (*Glaucomys sabrinus*), Townsend's chipmunks (*Tamias townsendii*), Siskiyou chipmunks (*T. siskiyou*), western red-backed voles (*Myodes californicus*), and southern red-backed voles (*Myodes gapperi*) using fecal pellet analysis. These rodents are truffle spore dispersers and prey for forest predators such as the northern spotted owl (*Strix occidentalis caurina*). Pretreatment diets showed differences in truffle and plant consumption among genera. Tree harvesting, especially in the 15% aggregated retention pattern, reduced frequency of Rhizopogon spores in the diet of voles, which may reflect a reduced ability of these animals to forage for Rhizopogon truffles, a decreased access to these truffles, or a reduction in Rhizopogon truffle abundance or frequency. Habitat island effects and edge effects provide conceptual frameworks for the reduction in consumption of Rhizopogon truffles by voles in green-tree aggregates. Overall, small mammal consumption of truffles showed little change in response to the treatments. Animals may be compensating for a locally declining food source by altering their foraging behavior. The long-term effect of this postulated behavioral compensation on small mammal energetics and population dynamics is unknown. Forest managers may reduce the impact of tree harvesting on these key forest ecosystem components by including green-tree aggregates within a dispersed retention matrix. [*Myodes* is a taxonomic revision of *Clethrionomys*]

◆ **Johnson, C.N. 1996.** Interactions between mammals and ectomycorrhizal fungi. Trends in Ecology and Evolution 11:503-607 [M]

Author abstract. Many ectomycorrhizal (ECM) fungi produce fruit-bodies below ground and rely on animals, especially mammals, for dispersal of spores. Mammals may therefore play an important role in the maintenance of mycorrhizal symbiosis and biodiversity of ECM fungi in many forest ecosystems. Given the pivotal role played by mycorrhizal fungi in the nutrition of their plant hosts and, possibly, in the determination of plant community structure, the ecological significance of mycophagous mammals may extend to the productivity and diversity of plant communities. Mycologists and mammalogists have been aware of the interaction between their study organisms for many years, but recent research has produced new insights into the evolution of mammal-vectored spore dispersal among ECM fungi, the ecological importance of mycophagy to small mammals, and the effectiveness of mammals as spore-dispersal agents.

Notes. Epigeous fungi (mushrooms) disperse spores by wind, and semi-hypogeous fungi ("puff balls") that disperse spores by rupturing of the peridium. In contrast, hypogeous fungi (truffles) require small mammals to dig up and eat the fruiting bodies for spore dispersal [Caldwell et al. 2005:167 excavation by soil microorganisms also]. Hypogeous species are thought to have evolved in environments of "…low soil moisture, and the presence of physical barriers to mushroom emergence, such as freezing of soil." "Hypogeous species are a major part of the flora of ECM fungi in alpine and subalpine regions and in forests subject to seasonal drought in North America and Australia" (p. 504). Fungi are of low nutritional quality, composed primarily of complex carbohydrates with N bound in cell walls, indigestible spores, and non-protein forms of low value to mammals. However, they represents a moderate contribution to diet when it is highly available in fall as other forms of food become scarce or decline in nutritional quality. Truffles are eaten by small mammals in much greater proportion than mushrooms, possibly because truffles grow more in patches that are efficient to process, given the low nutritional gain.

Limited evidence suggests that ECM fungi are highly structured, such that neighboring trees are infected by genetically distinct fungal clones. Mycophagy is likely to result in high incidence of effective spore dispersal because small mammals may range over radii of several hundred meters, resulting in genetic outcrossing. Also, "mycophageous mammals will naturally tend to forage near trees that host ECM fungi, so that movement of spores should be directed toward sites that are suitable for germination and growth" (p. 505). Finally, "mammals can also move spores between distinct patches of habitat, and could play an important role in establishing ectomycorrhizal symbiosis in early successional habitats" (p. 506), including recent burns. Despite the strength of relationships described to date, "no study has yet produced direct or experimental perimental confirmation that mycophagy results in effective spore dispersal under field conditions. Also, we have too little information on the mechanisms by which ECM fungi typically colonize root systems - by vegetative growth or by dispersal of sexual spores -to predict what impact the removal of mycophagous mammals would have on mycorrhizal symbiosis, fungal diversity and genetic variance within populations of ECM fungi, or to guess at the time scales over which such impacts would be felt. It is important that these questions be answered by new research, as they have a direct bearing on the management of small mammals in forests, especially forests used for intensive timber production."

◆ **Kielland, K., Bryant, J. P. and Ruess. R. W. 1997.** Moose herbivory and carbon turnover of early successional stands in interior Alaska. Oikos 80:25-30.

Author abstract: In the taiga of interior Alaska, early successional stands are dominated by deciduous species. These species represent the main forage base for many mammalian herbivores. In a long-term study employing large, permanent exclosures, we measured the impact of winter browsing by moose and snowshoe hares on carbon flux in riparian willow/alder communities. We found that browsing-induced changes in leaf litter chemistry increased the rate of litter decomposition both in the laboratory and under field conditions, and increased the pool of mineralizable carbon in litter. The aboveground input of higher-quality litter-carbon following browsing may explain the increased respiration potentials of soils sampled outside the exclosures. Moreover, winter browsing tends to reduce the production of fine roots and appears to decrease fine root longevity. Thus, the net effect of moose browsing on aboveground and belowground processes in these early successional stands is to accelerate carbon turnover. These

results demonstrate that the effects of mammalian herbivory on element cycling in taiga is a two-stage process, involving intraspecific as well as interspecific responses at different time scales. Winter browsing by moose offer one example of how mammalian herbivory modify ecosystem-level processes that govern major functions in these ecosystems.

Notes: Exclosures were constructed in 1988 in the floodplain of Tanana River near Bonanza Creek Experimental Forest. The study occurred . The authors examined the effect of winter browsing by moose (*Alces alces*) and snowshoe hare (*Lepus americanus*) on primary succession of willow (*Salix* sp.) and alder (*Alnus tenuifolia*) communities in interior Alaska in 1994 when density was ca. 2.5 moose/mi^2 [this was prior to monitoring the hare abundance cycle, but the first year of sampling in 1999 was likely near the peak, so 1997 would likely have been during increase phase]. In contrast to earlier studies, which have concluded that herbivory decreases organic matter turnover and element cycling in late successional conifer forest, the authors show that herbivory increases these factors in the early successional forest, in which most browsing occurs. The short-term respiration rate of leaf litter from browsed plants was significantly greater than that of unbrowsed plants, and almost 30% more mineralizable carbon was available in browsed than unbrowsed litter. The authors conclude that herbivory facilitates vegetation change from willow to alder and associated nutrient cycling in young forest (< 50 years) in a manner that contributes to conifer dominance and soil nutrient conservation in more mature forest stands (50-100 years or more).

◆ **Krebs, C.J., S. Boutin, and R. Boonstra. 2001.** Ecosystem dynamics of the boreal forest: the Kluane Project. Oxford University Press, New York. 511 p.

Author introduction excerpt. In this book we describe the Kluane Boreal Forest Ecosystem Project, which operated from 1986 to 1996 in the southwestern Yukon. We begin by describing the area and its physical setting and then describe the background of the project and the wisdom that had accumulated to 1986 on how this system might operate. The details of the experiments we set up are presented, partly to help the reader appreciate the difficulty of working at -40° and partly to help those contemplating doing similar experiments in the future. Then we examine the three trophic levels of the plants, the herbivores, and the predators in detail to provide some surprises about how the individual species operate within the overall system. Finally, we synthesize these findings in a model of the boreal forest vertebrate community and provide an overview of what we have discovered and what remains to be done.

Notes: This text summarizes experimental manipulations of the boreal forest food web to understand factors causing bird and mammal population dynamics and community organization in southwestern Yukon during 1987-1996. The research was intended to occur over an abundance cycle of snowshoe hares of typically 8-11 years at high latitude. Vegetation studied in detail included herbaceous dicots, woody shrubs, and white spruce. Primary herbivores studied were snowshoe hares, ground squirrels, red squirrels, several vole species, and forest grouse. Major carnivores studied were lynx, coyotes, and raptors including great-horned owls. The primary models of ecosystem controls evaluated were nutrient limitation (bottom up) and predation (top down) through removal or addition experiments, specifically ground fencing (exclusion of carnivores or hares, but not raptors), nutrient supplementation (fertilizer or rabbit chow), and vegetation removal (herbicide). Research parameters included estimation of changes in nutrient concentration, abundance or biomass of plants and animals (including vital rates of survival and reproduction), and species interactions related to foraging ecology.

Red-back voles (*Clethrionomys rutilus*) were the primary forest species (abundance and biomass) that eats a wide range of foods dominated by seeds (berries), including spruce seeds and both epigeous and hypogeous fungi that can have symbiotic mycorrhizal relationships with tree roots to aid nutrient uptake. *Microtus* spp. are more grassland species that eat roots, stems, and leaves of monocotyledon and dicotyledon plants, with seeds being a small part of their diet. Fertilization had a modest positive effect on *Microtus* abundance, likely because it increased plant biomass. The major finding for *Clethrionomys* is that abundance is limited by overwinter survival, which is a function of overwinter food, not predation. Evidence from other research indicates overwintering berries from dwarf shrubs (e.g., blueberry) is key for overwinter survival, not spruce seed. Red-backed voles peak in abundance 2-3 years after peak of hares (secondary cycle), possibly because hare pellets fertilize berry shrubs. *Microtus* abundance in forested grasslands is likely limited by low primary productivity, which can be increased with fertilization.

Snowshoe hares normally avoid eating small spruce because of the anti-herbivory chemical camphor in juvenile trees, but at high hare density the apical shoot is typically eaten, slowing growth and exposing the trees to potentially multiple hare cycles before free-to-grow stage. Fertilization decreased camphor, as did exclusion of hares. Causation of the hare cycle was judged to be a simultaneous interaction of food supply and predation by lynx, coyotes, and raptors; these combined factors received stronger experimental evidence than either factor alone. Relatively few hares die of starvation, and both arctic and red squirrels are predators of neonatal hares. The primary finding overall for the various experiments was that the boreal forest community in Yukon is predominantly a top-down (predation driven) system. Limited information about Siberian boreal forest suggests its ecosystem dynamics might be relatively similar to boreal forest in North America, which is dominated by snowshoe hares as a keystone species [*last paragraph of book, details not specified*]. However, Fennoscandian boreal forest has been relatively well studied and appears to be “completely different” because Eurasian mountain hares (*Lepus timidus*) are rare in Sweden and Finland, where boreal forest community seems to be dominated by 3-4 year cycles of voles and lemmings (e.g., Danell et al. 1998).

◆ **Laursen, G.A. 1985.** Mycorrhizae: a review of the importance of fungi from high-latitude forests of Alaska. Agroborealis 17:58-66. [H]

Compiler excerpts.

- “Virtually all cone-bearing trees of the boreal forest that extend into many parts of Alaska, including interior forests, demonstrate fungus…root relationships….These relationships [have] been made for Sitka and white spruce in Alaska…” (p. 58)
- “Woody plants of Alaska that have ectomycorrhizal associations are alder and birch (Betulaceae), true fir, hemlock, larch, pine, and spruce (Pinaceae), and poplar and willow (Salicaceae). Ectomycorrhizal associations with these plants are known to exist throughout Alaska, including Alaska's Arctic” (p. 61)
- “Importance to Agriculture and Forestry: Mycorrhizae are crucial to many….forest timber species and to the management of renewable forest resources, to say nothing of their

importance in maintaining dynamic nutrient balances in any ecosystem... Economically important tree species in the forest ecosystem of lnterior Alaska are assumed to develop mycorrhizae as seedlings….When a habitat is disturbed (by clear cutting or fire, for example), substrates supporting the spore innoculum may also be destroyed " (p. .65)

- Figure 1 shows a "mature white spruce forest ecosystem (Bonanza Creek Experimental Forest) in the Alaskan interior where many species of…hypogeous [fungi] are in mycorrhizal association with over- and understory plants…" (p. 58)

Notes. Hypogeous fungi (shown in Fig. 1 for mature white spruce forest) associate with root mycorrhizae and are known to be obligately dispersed by small mammals (voles, etc) in feces. This inoculum is likely important to forest soils in boreal Alaska, and is affected by forest retention practices.

◆ **Lyly, M. T. Klemola, E. Koivisto, O. Huitu, L. Oksanen, E. Korpimäki. 2014.** Varying impacts of cervid, hare and vole browsing on growth and survival of boreal tree seedlings. Oecologica 174:271-281. [M]

Author abstract. The negative impacts of mammalian herbivores on plants have been studied quite extensively, but typically with only a single herbivore species at a time. We conducted a novel comparison of the browsing effects of voles, hares and cervids upon the growth and survival of boreal tree seedlings. This was done by excluding varying assemblages of these key mammalian herbivores from silver birch, Scots pine and Norway spruce seedlings for 3 years. We hypothesised that the pooled impacts of the herbivores would be greater than that of any individual group, while the cervids would be the group with the strongest impact. Growth of birch seedlings advanced when cervids were excluded whereas growth of seedlings accessible to cervids was hindered. Survival of all seedlings was lowest when they were accessible to voles and voles plus hares, whereas cervids seemed not to influence seedling survival. Our results show that the impact of herbivores upon woody plants can be potent in the boreal forests, but the mechanism and strength of this link depends on the tree and herbivore species in question. Risk of abated stand regeneration appears highest for the deciduous birch, though there is need for seedling protection also in coniferous stands. The clear cervid-mediated growth limitation of birch also indicates potential for a trophic cascade effect by mammalian top predators, currently returning to boreal ecosystems.

Notes. This research took place in Scandinavia, however, several principles are potentially applicable to Interior boreal forests in Alaska. Birch seedling growth, but not seedling survival, benefitted most from moose exclosures. Survival was impacted most when seedlings were accessible to voles and hares. The magnitude of impact was dependent on the tree and herbivore species in question. Birch was at greatest risk, conifers less so. There is potential for top predators to mitigate the herbivore-caused reduction in tree growth and survival.

◆ **MacCracken, J.G. and L.A. Viereck. 1990.** Browse regrowth and use by moose after fire in interior Alaska. Northwest Science 64:11-18.

Author abstract. This study was undertaken to estimate the short-term effects of fire on plant response and moose *(Alces alces* Miller) browse following the Rosie Creek fire near Fairbanks, Alaska. The fire consumed forests of quaking aspen *(Populus tremuloides* Michx.), paper birch *(Betula papyrifera* Marsh.) and white and black spruce *(Picea glauca* (Moench) Voss, *P. mariana* (Mill.) B.S.P.). The fire began in late May 1983, was hot and fast moving, and burned over 3,000 ha. Browse regrowth was abundant within two months. Regrowth was from root and stump sprouting of quaking aspen, paper birch, and willow *(Salix* spp). Generally, aspen sites produced the most browse followed by white spruce, birch, and black spruce. Composition of the pre-fire plant community, which was directly related to stand age, strongly influenced browse regrowth. Seedling establishment of browse species was evident by the third growing season after the fire. Moose foraged in the burn the first winter after the fire. Browse use ranged from 1 to 46 percent and was greatest on willow. Estimates of browse use based on stem counts and biomass data were significantly correlated. Crude protein and mineral concentrations differed among browse species and decreased as time after the fire increased. This suggests that wildfire can have immediate benefits to moose by the production of substantial browse within a few months.

◆ **Mäntylä, E., T. Klemola, and T. Laaksonen. 2011.** Birds help plants: a meta-analysis of top-down trophic cascades caused by avian predators. Oecologia 165:143–151. [L]

Abstract: The tritrophic interactions between plants, herbivores and avian predators are complex and prone to trophic cascades. We conducted a meta-analysis of original articles that have studied birds as predators of invertebrate herbivores, to compare top-down trophic cascades with different plant responses from different environments and climatic areas. Our search found 29 suitable articles, with a total of 81 separate experimental study set-ups. The meta-analysis revealed that plants benefited from the presence of birds. A significant reduction was observed in the level of leaf damage and plant mortality. The presence of birds also positively affected the amount of plant biomass, whereas effects on plant growth were negligible. There were no differences in the effects between agricultural and natural environments. Similarly, plants performed better in all climatic areas (tropical, temperate and boreal) when birds were present. Moreover, both mature plants and saplings gained benefits from the presence of birds. Our results show that birds cause top-down trophic cascades and thus they play an integral role in ecosystems.

Notes. This metaanalysis indicates that plants benefit from birds with regard to leaf damage and plant mortality in multiple habitat types, including natural boreal habitats that considered *Vaccinium myrtillus, Pinus ponderosa* and *Salix* sp. Birds positively affected the amount of plant biomass, whereas effects on plant growth were negligible.

◆ **Maser, C., J.M. Trappe, and R.A. Nussbaum. 1978.** Fungal-small mammal interrelationships with emphasis on Oregon coniferous forests. Ecology 59:799-809. [M]

Author abstract. Most higher plants have evolved with an obligatory symbiotic relationship with mycorrhizal fungi. Epigeous mycorrhiza formers have their spores dispersed by air currents, but hypogeous mycorrhizal fungi are dependent upon small mammals as primary vectors of spore dissemination. Mammalian mycophagists defecate within the coniferous forest ecosystem, spreading the viable spores necessary for survival and health of the conifers. As one unravels and begins to understand the interrelationships between small-mammal mycophagists and mycorrhizal fungi, it becomes apparent that the various roles of small mammals in the coniferous

forest ecosystem need to be reevaluated. One can no longer accept such simplistic solutions to timber management as poisoning forest rodents to “enhance” tree survival. One must consider the direct as well as the indirect costs and benefits of timber management decisions if one is to maintain balanced, healthy coniferous forests.

Notes. Earlier observational studies of drying and storage of epigeous fungi (mushrooms) lead researchers to over-emphasize the importance of epigeous fungi in the diet of small mammals. This diet study was based on stomach contents and fecal samples from animals collected primarily in coniferous forest of western Oregon and review of data from other areas, including Alaska. It confirmed the preponderance of hypogeous fungi (truffles, 88% by frequency) in diet of voles and mice (Clethrionomys, Microtus, Zapus), flying and red squirrels (Glacomys, Sciurus), and insectivores (Sorex) inhabiting forests and burns [listing here limited to those genera found in boreal forest of Alaska]. “The northern red-backed vole, *Clethrionomys rutilus*, feeds more heavily on vascular plants and fruits than on fungi, perhaps because of seasonal fungal scarcity in its far northern habitat. Thirty-three stomachs of *C. rutilus* examined from Alaska contained 44% fungi by volume (Tables 4 and 5). The boreal red- backed vole, *Clethrionomys gapperi*, also feeds extensively on fungi but has a more variable diet than *C. rutilus*” (p. 806).

Logging disturbance may explain patterns in post-disturbance abundance of some small mammal species because of dietary preferences. “*Clethrionomys californicus* normally disappear from clearcuts within a year after logging and burning because they are left without their specialized food supply: hypogeous mycorrhizal fungi do not fruit without their coniferous hosts. *Microtus oregoni*, however, increase in numbers as their primarily herbaceous diet becomes available“ (p. 808).

◆ **McDonough, T.J., and E.A. Rexstad. 2005**. Short-term demographic response of the red-backed vole to spruce beetle infestations in Alaska. Journal of Wildlife Management 69:246-254. [H]

Author abstract. How small mammals are affected by habitat changes caused by forest insect epidemics is largely unknown. Our objective was to determine the influence of spruce beetle (*Dendroctonus rufipennis*) epidemics on the dynamics of northern red-backed vole (*Clethrionomys rutilus*) populations approximately 10 years post-infestation. We conducted a mark-recapture study on northern red-backed voles for 2 field seasons in the Copper River Basin, Alaska, USA, where recent beetle infestations were widespread. Using the robust sampling design, we produced estimates of vole abundance, survival, and recruitment in 3 locations that varied in their degree of beetle-induced spruce mortality. Vole abundance inversely related to the level of spruce mortality. Vole recruitment showed a larger contribution from both immigration and in situ reproduction in the low infestation site than in the medium and heavy infestation sites. No differences in vole survival were detectable across the 3 locations with varied beetle-induced spruce mortality levels. Measured vole food resources and protective vegetative cover did not vary greatly across infestation levels. Abundance and recruitment parameters indicate a negative change induced by spruce beetle infestations. However, the effect of beetles was not large enough to cause the variation in vole survival. Spruce mortality levels may need to be over 50% before greatly influencing the habitat and the demographics of northern red-backed voles.

◆ **Miquelle, D.G., and V. VanBallenberghe. 1988.** Impact of bark stripping by moose on aspen-spruce communities. Journal of Wildlife Management. 53:577-586.

Author abstract: We studied bark stripping by moose (*Alces alces*) in Denali National Park and Preserve (DNPP), Alaska, to determine the proportion or bark in the diet, consider what conditions Induce bark stripping, and assess the combined impact of stem breakage and bark stripping in a quaking aspen (*Populus tremuloides*) - white spruce (*Picea glauca*) community. Less than 4% or the diet was composed or aspen and willow *(Salix* spp.) bark. Spring protein content or browse was 3x that of bark. Moose appeared to eat bark when availability of browse was low. Bark stripping was most common among female moose in spring, when movements were restricted by limited mobility of their calves. Over 75% or the aspen and bebb willow (S. *bebbtana*) canopy trees in an aspen-spruce community were debarked by moose. The amount or bark removed and the percentage of the trunk circumference girdled were positively associated with mortality or aspen and balsam poplar (*Populus balsamifera*). In the understory, stem breakage by moose increased the probability of deciduous plant mortality. Moose may be increasing the rate or succession in the aspen-spruce community through deciduous tree mortality due to bark stripping and suppression of understory replacement through stem breakage.

Notes: Study area was high elevation (1600-3460 ft.) forest and shrub communities. It is an ecological extreme of moose habitat in that moose have relatively limited access to typical summer forages of herbaceous or aquatic vegetation, relying instead on woody stems and leaves throughout summer (Van Ballenberghe V., Miquelle D.G., MacCracken J.G. 1989. Heavy utilization of woody plants by moose during summer at Denali National Park, Alaska. Alces 25:31-35). Moose existed at relatively low density (<1/mi^2) typical of boreal forest in interior Alaska.

Bark of aspen, balsam poplar, and 5 species of willow composed <4% of the spring (1 May-10 June) diet. Moose concentrated their barking on stems of larger diameter than existed in the understory. Aspen and balsam poplar with >50% of trunk circumference barked had greater mortality than trees with <50% barking. Mortality increased dramatically when >75% of trunk circumference was girdled, but this only occurred in <15% of instances. Fifty-six and 44% of wounds healed on aspen and poplar, respectively, compared with only 9% on Bebb willow. Years of deep snow forced moose from higher elevation willow communities with abundance forage into lower elevation forest, where forage abundance was low and bark stripping high. "Although moose rarely fed on bark, there was a cumulative impact that resulted in a high proportion of trees in the aspen-spruce forest being affected" (p. 584), although mortality rate of canopy trees was low (7.5% aspen, 10.5% poplar). Stem breakage on willow is also discussed. Bark stripping appears to be associated with a shortage of forage at specific times and locations.

◆ **Mooney, K.A., D.S. Gruner, N.A. Barber, S.A. Van Bael, S. M. Philpott, and R. Greenberg. 2010.** Interactions among predators and the cascading effects of vertebrate insectivores on arthropod communities and plants. Proceedings of National Academy of Sciences 107:7335-7340. [L]

Theory on trophic interactions predicts that predators increase plant biomass by feeding on herbivores, an indirect interaction called a trophic cascade. Theory also predicts that predators feeding on predators, or intraguild predation, will weaken trophic cascades. Although past syntheses have confirmed cascading effects of terrestrial arthropod predators, we lack a comprehensive analysis for vertebrate insectivores—which by virtue of their body size and feeding habits are often top predators in these systems—and of how intraguild predation mediates trophic cascade strength. We report here on a meta-analysis of 113 experiments documenting the effects of insectivorous birds, bats, or lizards on predaceous arthropods, herbivorous arthropods, and plants. Although vertebrate insectivores fed as intraguild predators, strongly reducing predaceous arthropods (38%), they nevertheless suppressed herbivores (39%), indirectly reduced plant damage (40%), and increased plant biomass (14%). Furthermore, effects of vertebrate insectivores on predatory and herbivorous arthropods were positively correlated. Effects were strongest on arthropods and plants in communities with abundant predaceous arthropods and strong intraguild predation, but weak in communities depauperate in arthropod predators and intraguild predation. The naturally occurring ratio of arthropod predators relative to herbivores varied tremendously among the studied communities, and the skew to predators increased with site primary productivity and in trees relative to shrubs. Although intraguild predation among arthropod predators has been shown to weaken herbivore suppression, we find this paradigm does not extend to vertebrate insectivores in these communities. Instead, vertebrate intraguild predation is associated with strengthened trophic cascades, and insectivores function as dominant predators in terrestrial plant-arthropod communities.

◆ **Mowrey, R.A., G.A. Laursen, and T.A. Moore. 1981.** Hypogeous fungi and small mammal mycophagy in Alaskan taiga. Proceedings 32nd Alaska Science Conference, University of Alaska, Fairbanks. Pp. 120-121 (abstract only) [H]

Author abstract. Specimens of 5 genera of hypogeous fungi, or “true truffles and false truffles”, have been collected by the authors since 1974 in on-going studies within the interior belt of the Alaskan taiga. The findings constitute new records for northern distributions of these genera and will be reported on in a forthcoming issue of the journal Mycotaxon . It is well documented from studies conducted in the Pacific Northwest that these 5 genera of fungi are ectomycorrhizal and that small mammals there seek out and consume them. During periods of peak fruiting, hypogeous fungi may comprise as much as 100% of the diet of small mammals. Mature spores from the fungi are then deposited in fecal pellets and upon germination the vegetative mycelia have been shown to typically form mycorrhizal associations with the roots of woody plants in the Pacific Northwest. Thus, a direct relationship exists between hypogeous fungi and small mammals which is beneficial to the ecosystem. There is some initial evidence that these same relationships between small mammals, hypogeous fungi and woody plants occur also in Alaska and comprise adaptations to northern environments not previously described. Hypogeous fungi in white spruce ((*Picea glauca*) and black spruce (*Picea mariana*) ecosystems were located in the summer of 1980 while engaged in excavating areas containing pits freshly dug by small mammals---presumably red squirrels (*Tamiasciurus hudsonicus*) , flying squirrels (*Glaucomys sabrinus*) and northern red-backed voles (*Clethrionomys rutilus*). A mature 165-year old upland white spruce site at Bonanza Creek Experimental Forest, 30 km west of Fairbanks, Alaska, was found to contain two genera of hypogeous fungi: *Gauteria* and

Hysterangium. These have been tentatively identified as *Gauteria graviolens*, *Hysterangium separabile* and *Hysterangium* sp. All basidiomycetes (false truffles), these fungi were found in clusters mainly within a radius of 3 m around the stems of live white spruce at depths of 5 to 6 cm in the organic soil horizon. Some were also located within 3 m of live paper birch (*Betula papyrifera*) and American green alder (*Alnus crispa*). At the Washington Creek Ecology-Fire Experimental Area, a mature 50-year old upland black spruce site 40 km north of Fairbanks, sporocarps of *Elaphomyces granulatus* (ascomycete: true truffle) were found growing near roots of black spruce, paper birch and American green alder. Red squirrels, flying squirrels and red-backed voles were obtained concurrently with sporocarp collections. Analysis of digestive tracts for spores of these 3 genera of hypgeous fungi were made on several of the animals and is continuing. The hypogeous fungus *Melanogaster* sp. (basidiomycete) has been collected each year since 1974 from 2 sites near Fairbanks. The sites include an active thermokarst pit in an upland paper birch forest 4 km west of Fairbanks, where the fungus wa.s collected from the pit walls, and from 3 Tanana River island sites within the Bonanza Creek Experimental Forest. On the islands, the fungus was collected from erosion cracks on raised river benches in the transition zone between open and closed shrub successional stages. Dominant shrubs from the river collection sites include *Alnus incana*, *Salix alaxensis*, *Salix interior*, *Salix novae-angliae* and *Salix* [brilchycat=pa]. *Geopora cooperi* Harkness[f, Gilkeyae] (ascomycete) has been collected in an upland stand of mature quaking aspen (*Populus tremuloides*) from an exposed mound of mineral soil at an excavation site 8 km NW of Fairbanks. [resulting citation] Geml, Jozsef, Gary A. Laursen, Harris C. Nusbaum & D. Lee Taylor. 2007. Two new species of *Agaricus* from the Subantarctic. Mycotaxon 100:193-208.

◆ **Nichols, T.F. 2005.** Aspen coppice with coarse woody debris : a silvicultural system for interior Alaska moose browse production . Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 92 pp.

Author abstract. Browse production and use by moose (Alces alces gigas) in interior Alaska was investigated in 4 and 2-year-old quaking aspen (Populus tremuloides) coppice stands following clear-felling without removal of the mature aspen stems. Moose winter browse utilization, as related to distance from cover, coarse woody debris (CWD), and browse species composition, was quantified. Aspen terminal leaders were sampled to relate current annual growth (CAG) dry biomass (g) to leader diameter (mm). Stem density, current annual browse production, and browse use were estimated. Browse use was determined as 1) proportion of aspen stems browsed (stand scale), 2) proportion of browsed leaders per stem (stem scale), and 3) diameter-at-point-of-browsing (leader scale). Aspen sucker density ranged from 23,000-43,000 stems/ha. Terminal leader diameter was found to be a good estimator of individual stem CAG biomass. CWD did not impede moose utilization of stems. Browse use declined from mature stand edge to center (100 m). Beyond 15 m from mature stand edge browse use was low compared to that within 15 m of the stand edge. Clear-felling without removal of stems is a viable silvicultural method to reinitiate seral aspen in lieu of prescribed fire or mechanical treatments on south-facing hillsides.

◆ **Paragi, T.F. 2010.** Density and size of snags, tree cavities, and spruce rust brooms in Alaska boreal forest. Western Journal of Applied Forestry 25:88-95. [H]

Author abstract. To forecast the potential effects of forest management on wildlife habitat, I surveyed late-seral features in boreal forest near Fairbanks, Alaska. I sampled 75 randomly selected plots stratified among nine stand types to count and recorded physical characteristics of snags, cavity trees, and *Picea* spp. trees with rust brooms. Snag density differed among some stand types (range, $\bar{x}$ = 10 –72/ha) and increased with mean age of stand type, whereas cavity density (2–17/ha) and broom density (3– 46/ha) showed no trend with stand age. Only 15% of 199 cavity openings were large enough (>50 cm2) and had a shape (width:height ratio, 0.5–1.5) that made them likely to be suitable for use by larger birds or arboreal mammals. The oldest and most valuable stand type for timber harvest (*Picea glauca* >23 cm dbh) often had trees with larger cavity openings and larger broom volumes than trees in other types. I recommend retention of rare specimens of late-seral features, considerations for feature recruitment in managed forests, and further documentation of wildlife use and associated fitness.

Notes. Text contains brief review on wildlife use of these features, including both species that disperse fungal spores (flying squirrels) and prey on small mammals (owls, marten).

◆ **Patrick, D. A., C. Laxton, D. Ball, S. Collins, S. Korzek, C. Langevin, J. Vimislik. 2013.** A multi-scale evaluation of the effects of forest harvesting for woody biofuels on mammalian communities in a northern hardwood forest. Northeastern Naturalist 20:678-693. [L]

Author abstract. Research addressing the implications of forest harvesting for mammals has focused on different categories of silvicultural prescriptions. However, the effects of these prescriptions on forest structure can vary considerably, and categories of prescriptions rarely incorporate the market for which timber is being harvested. The latter information is important given the recent shift from conventional round-wood harvesting to whole tree removal for biofuels production, and corresponding reductions in post-harvest woody biomass left on-site. Our goal was to assess the effects of forest harvesting for biofuels on mammal species. Objectives included 1) evaluating how structural components influenced mammals, and 2) assessing the role of scale on species-habitat relationships. We sampled mammals in a 97-ha area of hardwood forest in the Adirondack Mountains in New York that had been partially harvested for biofuels in 2010. We used Sherman traps and track plates to assess the distribution of mammals. We captured 6 species of mammals in Sherman traps and identified 8 species using track plates. Mammalian species varied in their sensitivity to changes in habitat characteristics associated with biofuels harvest (coarse woody debris and slash). Our study reveals a complex suite of factors driving the response of mammals to variation in forest structure as a result of biofuels production. The harvesting practices used in the focal region are unlikely to lead to dramatic changes in the abundance and distribution of individual species of small mammals, but may influence the occurrence of common species including deer-mice and voles.

Notes. Understanding how to manage for small mammal communities is important consideration for forest managers, given that small mammals are seedling herbivores that also disperse fungi (important to root mycorrhizae and seedling establishment). This study indicates that managing for common species of small mammals is feasible based on documented responses to different harvest treatments and associations of certain species with coarse woody debris and slash. Given the role of some species of small mammal in dispersal of fungal spores and others in herbivory, understanding how to manage for small mammals is important. This study occurred in northern hardwood forests of New York but provides a "proof of principle" for design of harvest system evaluation in boreal forest of Alaska.

◆ **Pearce, J. and L. Venier. 2004**. Small mammals as bioindicators of sustainable boreal forest management. Forest Ecology and Management 208: 153-175. [L]

Author abstract. Small mammals such as mice and voles have potential as indicators of sustainable forest management. They have an important functional role in forests, they are economically important as prey for furbearer populations, and they respond to disturbance in a characteristic manner. In Ontario, Canada, several small mammal species have been suggested as bioindicators. However, strong year-to-year variation in population levels independent of forest disturbance means that very long time frames would be required to detect trends. Models of habitat supply have been suggested as a method of monitoring small mammals. We explore the feasibility of monitoring structural measurements and habitat supply for small mammal species using an area near White River, Ontario, Canada, as a case study. Small mammals were surveyed in the region for 3 years, and associations with mapped and stand level habitat attributes examined. Thirteen species were recorded, but only five species were recorded in sufficient numbers for habitat associations to be examined. The deer mouse and red-backed vole were recorded from all mature forest habitats, although both were more prevalent in mixed wood stands. Red-backed vole abundance was linearly related to stand age and the volume of downed logs. Deer mice were most abundant in recently clearcut stands, with abundance declining sharply in 5–15-year-old stands. They were also abundant in mature forest, where they were significantly associated with downed wood volume. Vegetation complexity was also significant for both species. Habitat supply maps for both species could be readily developed, and structural attributes modified by forest practices were important. However, strong year-to-year variation in the abundance of both species in mature forest prevented carrying capacities from being reliably assigned to habitat supply maps. Thus, while relative changes in the availability of high, medium and low quality habitat are identifiable, expected changes in minimum population size cannot be inferred. The effect of cumulative disturbances on the quality of available habitat is also unknown. Without this information, change in habitat supply cannot be used to assess the sustainability of forest management actions. We suggest that dynamic landscape meta-population (DLMP) models may provide one solution, and require further exploration as a sustainability assessment tool.

Notes. This paper affirms a linear relationship of red-backed vole abundance relative to stand age and volume of downed logs in boreal Ontario. In interior Alaska, red-backed voles are also the most abundant small mammal, with the potential to be an important disperser of mycorrhizal fungi for seedling establishment. This paper consequently provides guidance for how forests can potentially manage vole abundance and thereby the associated ecosystem services that voles provide.

◆ **Pelz, H-J. 2003.** Current approaches towards environmentally benign prevention of vole damage in Europe. Pages 233-237 *in* G.R. Singleton, L.A. Hinds, C.J. Krebs, and D.M. Spratt, editors. Rats, Mice and People: Rodent Biology and Management. Australian Centre for International Agricultural Research, Canberra. 560 p.

Author abstract: Voles are the most important field rodent pest in Europe and farmers need benign means of reducing damage to crops. In this paper, I review ideas discussed during a recent meeting in Braunschweig, Germany, on *Prevention of vole damage in organic farming*. Measures suggested include the installation of migration barriers, the use of secondary plant compounds specifically acting against voles, support of vole predators, diversionary feeding, and physical devices for early detection of vole infestations. These approaches show some potential but require further investigation before they can be recommended for practical use. A successful strategy for the prevention of vole damage will probably have to integrate several of the suggested methods.

Notes: The author cautions that experimental evidence is needed to verify the benefit of maintaining habitat diversity and provisioning shelter for small predators (e.g., debris for small mustelids, perches or nesting habitat for raptors) in managed landscapes as a means to control rodent abundance and reduce damage to crops, including trees on plantations. Evidence of winter damage to vegetation is often detected in spring, when mitigation is too late. The use of thermal imaging (infrared cameras) and sound detectors for physical detection of voles during winter would provide a timely option for damage mitigation, which may include trapping or gassing in areas where organic farming certification prohibits use of rodenticides.

◆ **Persson, I.-L., J. Pastor, K. Danell, and R. Bergström. 2005.** Impact of moose population density on the production and composition of litter in boreal forests. Oikos 108:297-306.

Author abstract: Recent studies of ungulates have revealed that selective foraging seems to be an important mechanism by which they can affect the structure and species composition of the plant community, and thus quantity (dry mass) and quality (chemical composition) of litter available for decomposers. Such changes in litter production may be especially important in N-limited systems like boreal forests. We chose moose (*Alces alces*) as study species to investigate this mechanism. Moose browse mainly in the tree and shrub layers year round, and because of their wide distribution and often high population densities, they can have a significant effect on litter production of trees and shrubs in Swedish boreal forests. The effects of herbivores may also vary along productivity gradients. We therefore simulated browsing and urine and fecal deposition corresponding to 4 different moose densities in exclosures along a pre-existing forest productivity gradient. Both litter quantity (g dry mass per m^2 and year) and contributions of C and N (g dry mass per m^2 and year) decreased with increasing level of simulated moose density. High moose densities over extended time can therefore reduce N contributions to soil and therefore eventually reduce site productivity in Swedish boreal forests. This effect of moose was mainly a result of decreased litter quantity, because contradictory to studies from North America, litter quality (C:N ratio and N contribution per mass unit of litter) was not affected by level of simulated moose density.

Notes: Authors collected moose fecal pellets and used urea solution as a proxy for urine to simulate nutrient return from moose into sites of artificial browsing (clipping). The highest densities simulated for winter were ca. 7.7 moose/km^2 that corresponded to 25-40% biomass removal of current annual growth twigs.

◆ **Peters, S., S. Boutin and E. Macdonald. 2003.** Pre-dispersal seed predation of white spruce cones in logged boreal mixedwood forest. Canadian Journal of Forest Research, 33: 33-40

Author Abstract: Predation of white spruce (*Picea glauca* (Moench) Voss) cones by red squirrels (*Tamiasciurus hudsonicus* Erxleben) was quantified in the mixedwood boreal forest of Alberta in cutblocks with seed tree retention and in adjacent uncut forest, during 3 years with varying levels of cone crop (1998, 1999, 2000). Percent cone loss was quantified by comparison of paired pre- and post-caching photographs of tree crowns. Cone loss from seed trees in cutblocks was significantly lower than from control trees in adjacent uncut forest (48.5 vs. 54.9%). Although the number of cones produced per tree declined by 42% and the percentage of trees producing cones declined by approximately 48% between 1998 and 2000, there was no corresponding increase in the percentage of cones harvested by squirrels. Percent cone loss was significantly lower from single seed trees in cutblocks, as compared with seed trees left in patches of more than 20 trees (33.4 vs. 50.5%). Cone predation significantly reduced the amount of seed available for natural regeneration using a seed tree system. Although blowdown may be reduced if seed trees are left in patches, leaving white spruce seed trees as singles in cutblocks may reduce the level of cone predation.

◆ **Pusenius, J. and R.S. Ostfeld. 2002.** Mammalian predator scent, vegetation cover and tree seedling predation by meadow voles . Ecography, v. 25, no. 4 (Aug. 2002) pp. 481-487.

Author abstract. Herbivores are thought to respond to the increased risk of attack by predators during foraging activities by concentrating feeding in safe habitats and by reducing feeding in the presence of predators. We tested these hypotheses by comparing tree seedling predation by meadow voles within large outdoor enclosures treated either with scent of large mammalian predators (red fox, bobcat, coyote) or a control scent (vinegar). In addition, we compared the distribution of voles in relation to naturally occurring variation in vegetation cover and the tendency of voles to attack tree seedlings planted in small patches with cover manipulation (intact, reduced or removed cover). Predator scent did not affect the rate or spatial distribution of tree seedling predation by voles, nor did it affect giving up densities (a surrogate of patch quitting harvest rate), survival rates, body size or habitat distribution of voles. In both predator scent and vinegar treatments voles preferred abundant vegetation providing good cover, which was also the site of almost all tree seedling predation. We conclude that large mammalian predator scent does not influence the perception by voles of the general safety of habitat, which is more strongly affected by the presence of cover.

◆ **Putman, W.E. and J.C. Zasada. 1985.** Raven damage to plastic seeding shelters in Interior Alaska. North. J. Applied For. 2(1985):41-42

Author abstract. Two types of plastic seeding shelters are being tested in interior Alaska for regenerating white spruce. Raven damage to shelters has been observed on sites seeded shortly after burning. Damage averaged 68% with cones and 50% with funnels on a burned upland site, and 26% with funnels on a burned floodplain site. Damage was highly variable and appeared to be related to time of sowing and vegetation development near the seedspots. Care should be taken when considering use of seeding shelters after burning.

◆ **Radvanyi**, **A. 1987.** Snowshoe hares and forest plantations: a literature review and problem analysis. Information Report NOR-X-290, Northern Forestry Centre, Canadian Forestry Service, Edmonton, Alberta. 17 p. [H]

Author abstract. Snowshoe hare damage to forest plantations in the Canadian prairie provinces is studied through an extensive literature review. Interrelationships of habitat and snowshoe hare populations are examined. Eleven general methods of snowshoe hare damage control based on silvicultural treatments and population controls are presented and examined. Several avenues of research needed to improve snowshoe hare damage control procedures are suggested.

Notes: Approaches to damage control in the review included silvicultural (habitat manipulation, herbicide, larger seedlings and repellant chemicals, and physical barriers to protect seedlings) and hare population (toxic baiting, physical removal, diversionary feeding, chemosterilants, and biological control). Recommendations to minimize hare damage in plantations included habitat manipulation, larger seedlings, physical barriers, and population control. With respect to research, "A team approach, including expertise in silviculture, plant ecology, soils, small mammal biology, chemistry, and economics, is fundamental to development of a viable solution to the snowshoe hare damage problem" (p. 13).

◆ **Radvanyi, A. 1970.** Small mammals and regeneration of white spruce forests in western Alberta. Ecology 51:1102-1105. [M]

Author abstract. The fate of 7,800 pesticide-treated and radiotagged white spruce seeds (*Picea glauca* (Moench) Voss var. *albertiana* (S. Brown) Sarg.) was studied under field conditions near Hinton, Alberta, Canada, from 1962 to 1967. Approximately 50% of spring-placed seeds were destroyed by small mammals within 4 months, whereas only 19% or less of winter-placed seeds were lost within a year. From five to six times more seeds germinated following the winter seeding operations than after the first spring seeding test. Calculated ground seed-eating small-mammal populations varied from 2.0 to 7.4 (average 4.5) animals per acre in spring and from 4.9 to 12.2 (average 8.1) in the fall. Percentages of seeds destroyed were more directly related to time of seeding than to the number of animals present.

Notes: Seeds were coated with a radio-isotope (scandium-46) and subsequently coated with endrin, arasan, and aluminum flake (pesticides) and dispersed at various seasonal dates in fall and winter as part of the experimental design. A portable scintillometer was used to confirm location of seeds (87%) for determining fate under magnification (unchanged, germinated, dessicated, or destroyed by insects or specified groups of rodent). Rodent abundance (primarily *Clethrionomys, Microtus, Peromyscus,* and *Sorex*) was assessed by mark-recapture, including voles, mice, flying and red squirrels, short-tailed weasels, and martens. Their finding was that small mammals and insects continue to destroy coniferous seeds even though they are treated with the highly lethal insecticide endrin.

The author hypothesized that seeds placed into snow may be largely unavailable to rodents that are confined to subniviean runways. Freezing, thawing, and moisture from melting snow covers many of the seeds with soil, and moisture is abundant during the time of rapid germination. In contrast, seeds placed out in June may encounter prolonged dry periods and take on "secondary dormancy," leading to sporadic germination throughout the first or even second growing season. A prolonged germination period would increase exposure of seeds to small mammal depredation.

◆ **Reimoser, F., and H. Gossow. 1996.** Impact of ungulates on forest vegetation and its dependence on the silvicultural system. Forest Ecology and Management 88:107-119

Author abstract: In order to obtain an understanding of the forest-ungulate compartment in the ecosystem with the aim of better management, the impact of ungulates on forest vegetation, as well as the impact of habitat structure and dynamics on ungulates (density, distribution etc.) and on the forest's predisposition to game damage were investigated. It is shown that browsing and peeling impact depends markedly on silvicultural techniques. The attractiveness of habitats for game depends not only on food supply, but also, to a high degree, on food-independent habitat factors such as terrain conditions, climate, edge effect, disturbance and competition impact, and thermal and hiding cover availability. Forests with a badly managed ratio of settling stimulus to available food act as 'ecological traps', where the food needed for the over-abundant game ungulates is taken increasingly by the twig browsing and bark peeling of timber species. In general, one can say that a clear-cut system is attractive to deer and chamois. It is easy to hunt in, but it is susceptible to game damage. In particular, clear cutting in narrow strips and reafforestation have a high predisposition to game damage. In contrast, selective silviculture results in a more balanced system with less impact by ungulate game on forest vegetation, though hunting might be more difficult. Higher deer densities need not be associated with greater browsing damage; such damage also depends strongly on the growing-stock target and the silvicultural system. If forestry practices are 'close to nature', an abundance of ungulates may also result in a greater density of forest regeneration and a better mixture of tree species. The potential impact of ungulates on forest regeneration, man-made disturbances of the ungulate-vegetation system, and silvicultural measures to avoid game damage are discussed.

Notes: This is a review of forest practices and studies in Austria on relationships between ungulates and their environment, particularly roe deer *(Capreolus capreolus)* and to some extent red deer *(Cervus elaphus)* and chamois *(Rupicapra rupicapra).* Three groups of studies occurred: forest regeneration with and without ungulates (fenced enclosures), effects of habitat structure on browsing, and potential for browsing damage based on silvicultural systems.

This paper has an excellent discussion section on theory of where and why ungulate damage to tree species occurs and the importance of clearly defining “damage.” The term “settling stimulus” refers to how managed forest mosaics can create attractive habitat that puts more browsers in close proximity to crop trees than would occur in natural disturbance regimes (“ecological traps”). This habitat influence means that “damage” can occur at any moose density, and reducing ungulate density may not cause a proportional reduction in damage (see also Hörnberg 2001, Forest Ecology and Management 149:141-151). Addressing damage to forests cannot be addressed solely with forest practices; it must also include stakeholders "with plans coordinated over large enough regions to be relevant for the game species of interest" (p. 116).

◆ **Richmond, A.P. 1985.** Moose-browsing damage in a recently thinned stand of sapling paper birch in interior Alaska. Agroborealis 1985, V. 17 (JAN. 1985) P. 7.

Author abstract. The University of Alaska's School of Agriculture and Land Resources Management has, since 1980, been conducting intensive research in the field of forest management with the goal of identifying economically and biologically feasible forestry practices for use in managing interior forests. One of the practices being examined is thinning, i.e., a portion of a stand is removed to promote growth on the remaining trees. Although thinnings normally decrease the total volume of timber which can be harvested from a stand, the value of the stand increases due to the large size of the trees at harvest. Thinnings can be done on both a commercial and precommercial basis depending on the tree species, the management objectives for the stand, and the anticipated value of the stand at harvest.
The trees removed in a commercial thinning can be sold as fuelwood, poles, pilings or sawlogs, thereby helping to pay the cost of thinning. Precommercial thinnings are performed in sapling stands where the material to be removed does not have any commercial value. In this case, the increase in value of the thinned stand has to be great enough to offset or justify the treatment cost. The response of the stands to the thinning treatments is being assessed with regard to diameter-height growth and post-treatment damage. Types of damage most common to thinned stands are windthrow, snow breakage, and insect attack. A recent precommercial thinning in a sapling paper birch stand suffered some browsing damage from moose which may have a bearing on future intensive management of this tree species. The potential for moose browse damage of the residual trees had been recognized prior to the thinning treatment.
The stand was known to receive heavy use in winter by moose, as evidenced by the large number of broken and browsed trees observed over the two previous winters. As many as four moose had been observed i11 the area at one time. During the thinning-treatment period, a moose which had apparently broken the tops of four residual birch trees was observed in a portion of the stand already thinned. Studies of moose feeding habits have found that paper birch is a major food source and comprises between 12 and 35 per cent of total diet (Peterson 1955). This is supported by other research that indicates birch is heavily used when available (McMillan 1953, Dodds 1960. Bergerud and Manuel 1968, Crete and Bedard 1975. Telfer and Cairns 1978). Palatability (preference) for birch has been rated as equal to willows (Hosely 1949).

◆ **Schickmann, S., A. Urban, K. Krautler, U. Nopp-Mayr, and K. Hacklander. 2012.** The interrelationship of mycophagus small mammals and ectomycorrhizal fungi in primeval, disturbed and managed Central European mountainous forests. Oecologica 170: 395-409. [L]

Author abstract. Small forest dwelling mammals are considered to be major consumers and vectors of hypogeous ectomycorrhizal (ECM) fungi, which have lost the ability of active spore discharge. Fungal spore dispersal by mycophagy is deemed an important process involved in forest regeneration, resilience and vitality, primarily based on evidence from Australia and the Pacific Northwestern USA, but is poorly known for Central European mountainous forests thus far. Small mammal mycophagy was investigated by live trapping and microscopical analysis of

faecal samples. All small mammal species recorded (*Myodes glareolus, Microtus agrestis, Pitymys subterraneus, Apodemus* spp., *Glis glis, Sorex* spp.) had ingested spores of ECM fungi, albeit in varying amounts. *My. glareolus* was found to be the most important vector of ECM fungal spores, both in quantity and diversity. Species of the genus *Sorex* seem to play a hitherto underestimated role as dispersers of fungal spores. *Glis g*lis is likely to be an important vector owing to its large home range. Hypogeous ECM basidiomycetes accounted for most spores found in the faecal samples. The frequency of various genera of hypogeous ECM ascomycetes and ECM epigeous fungi was much lower. Comparison with null models indicated a non-random structure of the mycophagy network similar to other mutualistic bipartite networks. Mycophagy can be considered (1) to contribute to nutrition of small forest mammals, (2) to play a pivotal role for forest regeneration and functioning by providing mycorrhizal inoculum to tree seedlings and (3) to be vital for reproduction and diversity of the still poorly known hypogeous fungi. [*Myodes* is a taxonomic revision of *Clethrionomys*]

◆ **Smith, M.C. 1967**. Red squirrel (Tamiasciurus hudsonicus) ecology during spruce cone failure in Alaska. Univ. of Alaska Fairbanks. Unpubl. M.S. Thesis. 68 pp.

Author abstract: Observations were made on a red squirrel population in a mature white spruce (Picea glauca) forest in the Bonanza Creek Experimental Forest (southwest of Fairbanks, Alaska) during two years of spruce cone crop failure (July 1964 and April 1966).

◆ **Smith, W.P. 2007.** Ecology of *Glaucomy sabrinus*: habitat, demography, and community relations. Journal of Mammalogy 88:862-881. [M]

Author abstract. A common arboreal rodent of boreal and montane coniferous forests, the northern flying squirrel (*Glaucomys sabrinus*) has several life-history traits typical of K-selected species. Density varies among forest types, with core areas of use centering on food patches. Density is largely limited by food, and to a lesser extent, suitable natal dens, but also is influenced by potential competitors and predators. Local abundance of *G. sabrinus* frequently is correlated with density of large trees and snags, shrub and canopy cover, prevalence of old-forest features (e.g., coarse woody debris), and abundance of hypogeous mycorrhizal fungi (truffles). Diet varies seasonally and among habitats, but truffles (spring and autumn) and lichens (winter) are most often reported. In some parts of its geographic range, *G. sabrinus* has a more diverse diet and lower reliance on truffles in forests with a depauperate arboreal small mammal community. *G. sabrinus* is a keystone species in the Pacific Northwest, because its diet facilitates an obligate mutualistic relationship between mycorrhizal fungi and some trees and shrubs and because it is essential prey for mesocarnivores and avian predators. *G. sabrinus* achieves its highest densities in old growth, but also occurs in secondary forests. Disturbance that reduces structural complexity, canopy cover, or the availability of large, decadent trees typically results in smaller populations through effects on food, den sites, or risk of predation. The fundamental niche of *G. sabrinus* may be broader than suggested by early research in the Pacific Northwest. Sustaining viable and well-distributed populations in heavily modified landscapes will depend on the capability of remaining forest habitat to sustain breeding populations without immigration, or functional connectivity among fragmented populations such that viable metapopulations will persist. Future research should focus on identifying habitat conditions that sustain breeding populations in modified habitats and determining whether *G. sabrinus* can migrate freely through a matrix of unsuitable habitat.

Notes. This research from coastal forest in Southeast Alaska includes a review of *G. sabrinus* ecology across its range, including observations that its diet can be narrow or specialized. Hypogeous fungi occur 5-15 cm beneath the forest floor and are patchy in distribution. "Truffles (and most fungi) favor cool, mesic to wet microenvironments with relatively large amounts of decayed logs or coarse woody debris across the forest floor …. For that reason, fungal communities purportedly achieve their greatest abundance (total biomass) and highest diversity in old growth, as compared to younger, managed forests …" The consistency with which *G. sabrinus* consumes truffles throughout its range year-round indicates that hypogeous fungi are a vital food resource" (p. 870). A description of habitat associations of potential value in maintaining this mammal in managed forest is provided.

◆ **Sullivan, T.P. and D.S. Sullivan. 2014.** Voles, trees, and woody debris structures as habitat: balancing forest crop protection and biodiversity. Crop Protection 60:70–77. [M]

Author abstract. Relatively homogeneous early successional habitats develop after clearcutting and wildfire that voles of the genera *Microtus* and *Myodes* may colonize and generate population fluctuations. In these habitats, vole populations may reach pest status by their feeding on newly planted tree seedlings. Strategic management of excess woody debris into piles and windrows helps diversify new clearcuts by enhancing populations of forest-floor small mammals, including voles, and some of their predators. This study tested the hypotheses (H) that (H_1) abundance of voles and incidence of feeding damage to tree seedlings will be higher in windrow than dispersed (conventional) sites of woody debris, and (H_2) there will be a gradient of damage with the highest incidence immediately adjacent to windrows. A third hypothesis (H_3) predicts that feeding damage to trees will increase in relation to windrow size. *Microtus* voles and red-backed voles (*Myodes gapperi*) were live-trapped for three years (2010–2012) in replicated sites with woody debris dispersed and in windrows at three study areas in the southern interior of British Columbia, Canada. Incidence of feeding damage and mortality to tree seedlings by voles was measured in all sites. Mean abundance of *M. gapperi*, *Microtus*, and total voles were all significantly ($P \leq 0.04$) higher (up to 3.4 times) in windrow than dispersed sites, and hence the abundance part of H_1 was supported. Mean annual percentage of trees damaged by voles was significantly ($P \leq 0.03$) higher in windrow than dispersed sites over the two winters and for cumulative incidence of damage, and hence the tree damage part of H_1 was supported. Mortality of trees followed this pattern but was not formally significant. Trees planted immediately adjacent to a windrow had significantly ($P < 0.01$) greater feeding damage than seedlings planted further away, and hence H_2 was supported. There were significant linear relationships between mean percentage of trees killed ($r = 0.67$; $P < 0.01$) and mean number of total voles, and also with mean volume of woody debris per meter length of windrow ($r = 0.98$; $P < 0.01$). Thus, H_3 was also supported. To minimize overall mortality of trees, it is likely worthwhile to not plant trees near windrows. Slightly reduced stocking (<5% net forest area) and potential loss of some trees to voles need to be balanced alongside biodiversity and conservation considerations provided by woody debris structures. [*Myodes* is a taxonomic revision of *Clethrionomys*]

◆ **Sullivan, T.P. and D.S. Sullivan. 2011.** Balancing pest management and forest biodiversity: Vole populations and habitat in clearcut vs. variable retention harvest sites. Crop Protection 30:833-843. [M]

Author abstract. Voles of the genus *Microtus* are long-standing pests in temperate and boreal forests of North America, Europe, and Asia where they feed on newly planted trees on cutover forest land. Clearcutting (CC) dominates forest harvesting and produces homogeneous habitats for voles. Variable retention (VR) harvests involve various partial cutting practices that produce heterogeneous habitat patterns compared with CC. This study tested the hypotheses (H) that compared to CC, VR harvesting will (H1) limit population size of *Microtus* and feeding damage to tree seedlings; (H2) provide some mature forest habitat for red-backed voles (*Myodes gapperi*); and (H3) enhance abundance and species diversity of the terrestrial small mammal community. *Microtus*, red-backed voles, and other forest-floor small mammals were live-trapped for three years (2007-2009) on "young" and "older" CC and VR sites near Golden, British Columbia, Canada. Mean basal area (BA) and density of overstory coniferous trees were significantly (P=0.03) higher in the young VR than CC sites. Abundance of herbaceous vegetation and grasses was similar in both harvesting systems at 3- and 5-years post-harvest. Although not statistically significant, the relatively higher numbers (2.3-2.9 times) of *Microtus* on CC than VR sites at 3-4 years post-harvest is suggestive that VR may reduce *Microtus* population size. However, the mean abundance of 35 *Microtus*/ha in VR sites at 3 years post-harvest was at the border-line of moderate to high risk of feeding damage. Based on equivocal levels of vole damage to plantation trees on CC and VR sites, the damage part of H1 was refuted. With respect to H2, VR harvesting did provide some forest habitat for red-backed voles, at least initially in the third year, and then again at 10-20 years, after VR cutting. Total abundance and species diversity of the terrestrial small mammal community were similar in CC and VR sites, and hence H3 was rejected. The mean BA (14.7 m2/ha) and density (73-127 trees/ha) of overstory (>10-20 m height) trees of our VR sites were insufficient to alter development of understory herbaceous vegetation and abundance of *Microtus*. Higher levels of VR should be investigated as a means of reducing this pest problem in young plantations.

Notes: Herbivory by *Microtus* voles can cause significant impacts on regeneration in both natural and planted boreal habitats. Red-backed (*Myodes*) voles, however, do not have such impacts. Other papers in this bibliography indicate that red-backed voles provide potentially important ecosystem services, such as dispersal of fungal spores associated with tree root mycorrhizae, which are important to seedling establishment and tree growth. This paper provides some helpful guidance on variable retention harvesting as a means to provide habitat for red-backed voles. Treatments presented in this paper did not impact *Microtus* abundance, but suggests higher levels of variable retention are worth considering. Southern red-backed vole in this paper (*M. gapperi*) is a different species than the northern red-backed vole from interior Alaska (*M. rutilus*). Given that both are the same genus, it seems reasonable to expect similar responses to harvest treatments. [*Myodes* is a taxonomic revision of *Clethrionomys*]

◆ **Sullivan, T.P., and D.S. Sullivan. 2010.** Forecasting vole population outbreaks in forest plantations: the rise and fall of a major mammalian pest. Forest Ecology and Management 260:983-993. [M]

Author abstract. Voles of the genera *Microtus* and *Myodes* feed on tree seedlings planted on cutover forest land in temperate and boreal forests of North America and Eurasia. This damage may have serious economic implications as well as limit regeneration of appropriate tree species in certain forest ecosystems. Prediction of vole population outbreaks and feeding damage to forest plantations, across even a limited geographic range, has yet to be achieved in North America. Thus, a major objective was a detailed analysis of changes in population dynamics of long-tailed voles (*Microtus longicaudus*), and to test three hypotheses (H) that vole populations would: (H1) rise and fall in accordance with the abundance of herbaceous plants (grasses and forbs) during early vegetative succession after forest harvesting, (H2) be positively associated with grass-seeded sites; and (H3) incidence of feeding damage to seedlings would be positively associated with vole abundance. Voles were live-trapped for 6 years (2004–2009) from the time of harvesting on intensive sites, as well as surveyed over a range of extensive sites. Population numbers were related to habitat characteristics and tree damage in young forest plantations near Golden, British Columbia, Canada.

Populations of long-tailed voles were low in the first two years after harvest with mean numbers <5–15/ha. Annual peaks of 49–84 voles/ha were recorded in 2006. In the fourth year (2007) after harvesting, numbers of voles declined on two of three sites, deepened in 2008 and reached extirpation in 2009. On the extensive sites, vole numbers increased 4.6–5.3 times from 1–2 to 3–6 years post-harvest before declining thereafter. Crown volume index of grasses and herbs, volume and abundance of downed wood, total species richness of vascular plants, and structural diversity of herbs were important habitat variables. Vole numbers were higher on those sites seeded with pasture grasses and forbs. There was a significant positive relationship of tree mortality and abundance of voles (*Microtus*) across a relatively wide geographic area.

This study is the first relatively long-term analysis of changes in population dynamics of the long-tailed vole and the predictions of H1 and H2 seemed to be supported. The positive relationship (H3) of the incidence of overwinter damage to trees and vole abundance is the first such analysis for forest plantations, on harvested sites, in North America. At 3–4 years post-clearcut harvesting is a critical time for population buildups of voles and subsequent damage to plantation trees. Seeded grass species clearly create optimum habitat conditions for voles, generating population densities up to 30–50 voles/ha, which is in the range of a “high” damage risk to seedlings. Risk ratings (voles/ha) for feeding damage to trees were low (<7), moderate (7–34), high (35–88), and very high (>88).

◆ **Sullivan, T.P. and D.S. Sullivan. 2008.** Vole-feeding damage and forest plantation protection: Large-scale application of diversionary food to reduce damage to newly planted trees. Crop Protection 27:775-784. [M]

Author abstract. Forest and agricultural crops periodically experience feeding damage from herbivorous rodents such as voles of the genera *Microtus* and *Clethrionomys*. This problem has a long history, which needs a management solution that is both economically and ecologically viable. This study tested the hypothesis that large-scale (6–16 ha) application of diversionary food would reduce vole-feeding damage to newly planted trees. Four overwinter Experiments (A, B, C, and D) were conducted with long-tailed vole (*Microtus longicaudus*) populations in new forest plantations of lodgepole pine (*Pinus contorta*), Douglas-fir (*Pseudotsuga menziesii*),

and interior spruce (*Picea glauca, Picea engelmannii*) near Golden, British Columbia, Canada, from 2003 to 2007. Diversionary food ''pucks'' were composed of Douglas-fir bark mulch and alfalfa (*Medicago sylvatica*) pellets/meal mixed with canola (*Brassica rapa*) oil and wax. Mean percentage (±SE) survival of trees was similar (P=0.18) between control (72.6±11.8) and food (86.2±8.7) sites in Experiment A. Experiment B had intensive feeding by voles and near exhaustion of the food supply in three of five replicates, with no statistical difference (P=0.11) between control and treatment sites. This pattern continued in Experiment C with total tree survival appearing highest (P=0.06) in the intermediate puck density. Mean (±SE) percentage survival of total trees was significantly (P=0.05) higher in food (85.0±6.3) than control (62.5±14.3) sites in Experiment D. Despite these variable results, in those experimental units with substantial feeding pressure by voles and a sufficient overwinter supply of diversionary food, tree survival was 20–25% higher in food than control sites. If food can help maintain sufficient trees on a site and it is required for only one or two winters, diversionary feeding may be an economical and ecological solution to this significant reforestation problem.

Notes: *Microtus* voles can cause significant damage to tree crops. This paper shows the possibility to mediate damage to trees via use of a diversionary food source for voles.

◆ **Sullivan, T.P., and D.S. Sullivan. 1982.** Barking damage by snowshoe hares and red squirrels in lodgepole pine stands in central British Columbia. Canadian Journal of Forest Research 12:443-448.

Author abstract: Barking damage by snowshoe hares *(Lepus americanus* Erxleben) and red squirrels *(Tamiasciurus hudsonicus* Erxleben) is common in overstocked stands of juvenile lodgepole pine *(Pinus contorta* Dougl.) in central British Columbia. Average proportion of potential crop trees damaged by hares was 30.0% and by squirrels was 37.7%. Most hare feeding injuries occurred in heavily stocked (> 20 000 stems/ha) stands whereas squirrel damage was most common in less dense stands. Both animal species damaged trees in thinned stands, and hence may have a serious impact on stocking control programs in lodgepole pine.

Notes: [Lodgepole pine is a species being considered for further experimental planting in Alaska because it is predicted to be productive in a warmer drier climate.] Hares feed on the bark and underlying cambium layer of pine stems whereas squirrels peel off the bark to feed on the cambium and phloem tissues. Bark damage was considered of little importance to forest management until the advent of intensive silviculture of young sapling or pole-sized conifers. "Juvenile lodgepole pine *(Pinus contorta* Dougl.) covering burned-over forest land have become increasingly valuable to forestry in western North America. This species shows favourable growth and yield responses to silvicultural treatments such as stocking control (thinning or spacing). However, over-stocked pine stands provide optimum habitat for populations of snowshoe hares that can cause a serious damage problem for crop trees in natural and thinned stands of lodgepole pine" (p. 444). Hares clip the leader and lateral shoots in addition to barking to the extent of girdling. Barking injuries in pine stands have also been reported for squirrels and porcupines. The percentage of crop trees damaged by hares increased with stocking density (decreasing stem diameter), whereas the percentage of crop trees damaged by squirrels decreased with stocking density, suggesting hares concentrated feeding in dense stands with cover whereas squirrels preferred larger crop trees. For squirrels, shoot clipping and cone and seed removal are considered of greater importance than barking.

Avoiding hare damage on lodgepole pine might best be accomplished by avoiding thinning during the 2-3 years of peak hare abundance and damage occurs. Localized population reduction is unlikely to be effective at reducing damage because of rapid repopulation from surrounding areas, particularly during periods of cyclic abundance.

◆ **Sullivan, T.P., D.S. Sullivan, P.M.F. Lindgren, D.B. Ransome, J.G. Bull, C. Ristea. 2011.** Bioenergy or biodiversity? Woody debris structures and maintenance of red-backed voles on clearcuts. Biomass and Bioenergy 35:4390-4398. [M]

Author abstract. Wood residues from forest harvesting or disturbance wood from wildfire and insect outbreaks may be viewed as biomass "feedstocks" for bioenergy production, to help reduce our dependence on fossil fuels. Biomass removals of woody debris may have potential impacts on forest biodiversity and ecosystem function. Forest-floor small mammals, such as the southern red-backed vole (*Myodes gapperi*) that typically disappear after clearcut harvesting, may serve as ecological indicators of significant change in forest structure and function. We tested the hypothesis that large piles and windrows of woody debris would enhance the population dynamics (abundance, reproduction, and survival) of *M. gapperi*, compared with a dispersed treatment on clearcut sites. We also investigated the trade-offs in values and functions between the apparently competing uses of bioenergy or biodiversity. Red-backed voles were intensively live-trapped from 2007 to 2009 in replicated woody debris treatments of dispersed, piles, windrows, and uncut mature forest at each of two study areas in south-central British Columbia, Canada. Our hypothesis was supported, at least on sites with substantial woody debris structures. Here we show, for the first time, that constructed piles and windrows of woody debris maintain habitat for red-backed voles, and presumably some components of biodiversity, on clearcuts. Woody debris from harvested sites can be used for bioenergy production, but this depends on the interplay between volume, transportation distance, plant capacity, and electricity price. These variables define the economic value of woody debris and we feel this is an indirect expression of the value of biodiversity. The response of policy makers will reflect how we prioritize the challenge of managing biodiversity as we develop new sources of renewable energy.

<u>Notes</u>. Red-backed (*Myodes*) voles potentially important ecosystem services, such as dispersal of fungal spores associated with tree root mycorrhizae, which are important to seedling establishment and tree growth. They are also key prey items for many predators within interior Alaska forest. This paper provides some helpful guidance on woody debris retention as a means to provide habitat for red-backed voles, and considers the economic tradeoffs of vole retention versus use of the debris for biomass in clear cuts. [*Myodes* is a taxonomic revision of *Clethrionomys*]

◆ **Taylor, D. L., I. C. Herriott, K. E. Stone, J. W. McFarland, M. G. Booth, and M. B. Leigh. 2010.** Structure and resilience of fungal communities in Alaskan boreal forest soils. Canadian Journal of Forestry Research 40:1288-1301.

Author abstract: This paper outlines molecular analyses of soil fungi within the Bonanza Creek Long Term Ecological Research program. We examined community structure in three studies in mixed upland, black spruce (*Picea mariana* (Mill.) BSP), and white spruce (*Picea glauca* (Moench) Voss) forests and examined taxa involved in cellulose degradation at one upland site. We found that soil horizon was the factor by which fungal communities were most strongly structured and that predictable turnover in upland fungal species occurred through succession. Communities from consecutive summers were not significantly different, indicating that interannual variation was small in relation to differences between forest types and soil horizons, yet the community at a seasonal study site underwent significant changes within a year. In each study, mycorrhizal fungi dominated the community. Fungi rather than bacteria appeared to dominate [^{13}C] cellulose degradation, with strongest growth in taxa that were not dominant members of the untreated community, including members of the genus *Sebacina*. Overall, our results point to considerable interannual resilience juxtaposed with narrow niche partitioning and the capacity of individual taxa in these hyperdiverse communities to respond strongly to resource inputs and changes in other abiotic environmental parameters such as temperature. Our data double the cumulative total of fungal sequences in GenBank and together achieve a better picture of fungal communities here than for any other ecosystem on earth at this time.

Notes: This particular study examined soil fungi of upland mixed forest, white spruce, and black spruce. Fungi present are predominantly associated with root mycorrhizae. Each forest type shows its own fungal community which stays constant between seasons. Combined with the previous study, we know that soil fungi of boreal Alaska forests are very diverse and currently among the best studied in the world.

◆ **Taylor, D. L., T. N. Hollingsworth, J.W. McFarland, N. J. Lennon, C. Nusbaum, and R. W. Ruess. 2014.** First comprehensive census of fungi in soil reveals both hyperdiversity and fine-scale niche partitioning. Ecological Monographs, 84(1), 2014, pp. 3–20

Author abstract. Fungi play key roles in ecosystems as mutualists, pathogens, and decomposers. Current estimates of global species richness are highly uncertain, and the importance of stochastic vs. deterministic forces in the assembly of fungal communities is unknown. Molecular studies have so far failed to reach saturated, comprehensive estimates of fungal diversity. To obtain a more accurate estimate of global fungal diversity, we used a direct molecular approach to census diversity in a boreal ecosystem with precisely known plant diversity, and we carefully evaluated adequacy of sampling and accuracy of species delineation. We achieved the first exhaustive enumeration of fungi in soil, recording 1002 taxa in this system. We show that the fungus : plant ratio in *Picea mariana* forest soils from interior Alaska is at least 17:1 and is regionally stable. A global extrapolation of this ratio would suggest 6 million species of fungi, as opposed to leading estimates ranging from 616 000 to 1.5 million. We also find that closely related fungi often occupy divergent niches. This pattern is seen in fungi spanning all major functional guilds and four phyla, suggesting a major role of deterministic niche partitioning in community assembly. Extinctions and range shifts are reorganizing biodiversity on Earth, yet our results suggest that 98% of fungi remain undescribed and that many of these species occupy unique niches.

Notes: Soil fungi of boreal Alaska forests are very diverse and currently among the best studied in the world. This papers focuses on fungi found in Alaska black spruce forest, and taxa recorded in this study greatly increases the predicted number of soil fungi estimated to occur globally.

◆ **Weixelman, D.A., R.T. Bowyer, and V. Van Ballenberghe. 1998.** Diet selection by Alaskan moose during winter: effects of fire and forest succession. Alces 34:213-238.

Author abstract: The authors studied forage available to and used by Alaskan moose during the winter of 1988-1989 on the Kenai Peninsula, Alaska, USA, to test the hypothesis that changes in the quality and abundance of browse during winter affected selection of diet. Overall, moose browsed scouler willow, Kenai birch, and aspen in proportion to their availability, and avoided black cottonwood. Plant secondary compounds offer a likely explanation for moose avoiding cottonwood and not consuming white spruce. Percent use of a browse species, however, was not significantly related to its availability or to those measures of nutrient content that were analyzed. Black cottonwood was not browsed to a greater degree in stands with low resource availability, contrary to a prediction of optimal foraging theory. Patterns of diet selection did not vary between periods of winter even though abundance of forage did so. Distance from escape cover affected diet selection by moose; selectivity of diet declined with increasing distance from cover, indicating risk of predation played a role in the foraging dynamics of moose. The use of fire holds the potential to improve habitat for moose, but the population dynamics of this large herbivore also need to be considered for such management to be effective. Likewise, the sound management of moose requires that suitable habitat be available in other seasons as well as winter.

Notes: Diet selection was calculated by browse species use relative to its availability (Fig. 11) for stands 7-10, 20-30, and 70-80 years old. The ratio was >1 for Scouler willow (selected) and <1 for Alaska birch, quaking aspen, and black cottonwood (avoided).

◆ **West, S.D. 1982.** Dynamics of colonization and abundance in central Alaskan populations of the northern red-backed vole, *Clethrionomys rutilus.* Journal of Mammalogy 63:128-143. [H]

Author abstract. Population dynamics of *Clethrionomys rutilus* and *Microtus oeconomus* were examined during colonization of a severely burned (July1971) area of black spruce forest, located 40 km north of Fairbanks, Alaska. Live trapping from June 1972 to September 1976 on two trapping grids, one in burned and the other in unburned forest, revealed that colonization of the burned area by *Clethrionomys* was gradual, characterized by midwinter abandonment until food and cover resources were sufficient to allow overwintering in 1975, four years after the fire. Reproduction did not occur on the burned area during the first two post-burn years. Despite establishment of a resident population in 1975, recruitment was dependent upon immigrant voles, particularly pregnant females. A high rate of immigration into recently burned areas, and hence successful colonization, is possible for *Clethrionomys* because source populations exist in all areas of mature forest. *Microtus oeconomus,* captured only twice on the unburned area, arrived on the burned area in 1974, three years after the fire. However, *Microtus* density was low, and the population consisted primarily of transient voles. *Clethrionomys* density underwent a simple sequence of annual fluctuations. In unburned forest, peak density, variable from year to year, was reached in the fall, and low densities occurred yearly in early summer. Density was high in 1974 and 1975, low in 1972, 1973, and 1976. High 1974 and 1975 densities were due to increased reproductive output, especially of first generation (spring-born) females. Stomach content analysis indicated that *Clethrionomys* relied heavily upon the fruits of several berry-producing plants in all seasons. The phenology of central Alaska fruit production results in fruit scarcity in early summer, it is hypothesized that this variable strongly influences population density each year and perhaps the amplitude of the annual cycle of abundance.

Notes. This paper was cited in Krebs et al. (2001:216) as putative evidence of small mammals as potential fungi dispersers into recently burned areas. Dietary data on fungi are brief (Tables 3 and 4) and do not specify hypogeous fungi most associated with mycorrhizal innoculation. However, Maser et al. (1978) described hypogeous fungi data specific to *C. rutilis* in interior Alaska and cites Robert L. Rausch as the source (Rausch worked extensively in Alaska during 1950s and 60s).

Berries collected from stomachs of *C. rutilis* in early April suggest berries are the primary overwintering food. Midwinter abandonment of burned areas during the first 3 years post-fire occurred likely through emigration and mortality because of inadequate food and lack of vegetative cover. Vole winter aggregation in areas of thick moss despite abundance of subnivean berries in adjacent habitats (and intraspecific strife in other seasons) suggests the importance of insulation in colonization of burned areas. Accumulation of *Calamagrostis* debris may have aided insulation in some areas. [The subnivean environment in itself provides substantial insulation against low temperature extremes if adequate snow depth exists at low snow density].

◆ **Wolff, J.O. and J.C. Zasada. 1975.** Red squirrel response to clearcut and shelterwood systems in interior Alaska. USFS Research Note PNW 255. 7 pp.

Author abstract. Population response of red squirrels to clearcut and shelterwood silvicultural systems in interior Alaska was determined by counting the population before and after cutting. Following harvest, all territories from the clearcuts were vacated, and the number of squirrels in the shelterwood decreased from 1 per 0.69 ha to 1 per 2.0 ha. The squirrel population in the adjacent control area remained stable.

Section 7
INSECTS AND DISEASES

SUMMARY

Roger Burnside, Alaska Department of Natural Resources, Division of Forestry (Retired); Nicholas Lisuzzo, U.S.D.A. Forest Service, State and Private Forestry

The management and study of forest insects and diseases in Alaska are influenced by challenges not typically encountered in the Lower 48 states. The remote nature of most of Alaska's forests, its paucity of forest health technical experts, and the relatively small body of relevant scientific literature combine to create a unique environment for forest managers. With the advance of integrated geographic information systems, landscape-level surveys have become more common for the analysis of forest disturbances, which previously were not economically practical.

The following annotated bibliography provides a cross-section of both peer-reviewed publications and technical reports that should be considered in pre- and post-harvest planning for enhancing the reforestation of insect and disease impacted stands in Alaska FRPA Regions II and III.

The effects of tree-killing bark beetles should be of primary consideration when planning both regeneration and reforestation activities in Regions II and III (Beckwith et al. 1977; Boggs, et al. 2008; Burnside 1991; Burnside and Mahal 2003; Burnside et al. 2011; Fettig, et al. 2011; Hard and Holsten 1985; Holsten et al. 1979; Holsten 1994; Holsten 1998; Packee 1997; Ross et al. 2001; Schulz 1996; Schulz 2000). In Alaska, many of the areas impacted by primary tree-killing bark beetle species, such as the spruce beetle (*Dendroctonus rufipennis* Kirby), have been repeatedly infested over the years (Holsten 1990).

A significant body of work tied to bark beetle effects on reforestation potential, primarily from FRPA Region II, can be found in this section of the bibliography. Of particular interest is the 2006 Journal of Forest Ecology and Management special issue focusing on "Spruce beetles and forest ecosystems of south central Alaska." The papers included therein present both an exhaustive review and synthesis of 30 years of previous research findings (Werner et al. 2006), and new insights from seven original research papers. These latter papers provide fresh perspectives into the ecological and socioeconomic effects of spruce beetle outbreaks as viewed by local residents living in infested landscapes (Flint, 2006; see also: Flint 2007); long-term natural disturbance regimes and disturbance return intervals by spruce beetles (Berg, Henry, Fastie, De Volder and Matsuoka, 2006b) and fire in bark beetle impacted forests (Berg and Anderson, 2006; Readers are also directed to references in Section 5 of this bibliography: "Fire and Regeneration"; specifically: Berg et al. 2006a); effects of outbreaks on landscape-level stand dynamics (Allen et al. 2006), plant succession (Boucher and Mead 2006), berry production (Suring et al. 2006); and the effects of different management prescriptions on impacted forests (Goodman and Hungate, 2006).

Spruce beetle outbreaks can significantly alter stand composition and structure (Holsten et al. 1995). Recent research suggests that although some infested areas (e.g. Copper River Basin and southern Kenai Peninsula lowlands) will be slower to reforest owing to few trees and seedlings, there does not appear to be an overall, widespread reduction in regeneration following the massive 1990s spruce beetle epidemic. On the Kenai Peninsula, plant diversity, including spruce regeneration, can also be reduced due to the competitive advantage of competing vegetation such as bluejoint grass (*Calamagrostis canadensis*) and fireweed (*Chamerion angustifolium*). However, this pattern of understory growth was not observed in the Copper River Basin (Allen et al. 2006; Matsuoka et al. 2001). Natural regeneration of Lutz (*Picea* x lutzii) and white spruce (*Picea glauca*) is often inadequate to meet reforestation standards due to the low persistence of seeds in the soil, a sporadic seed production cycle, and inadequate site conditions for spruce seedling establishment. Changes in seedling composition after spruce beetle outbreaks and the resulting understory response can still vary markedly both in magnitude and direction among geographic regions as evidenced by a vegetation composition analysis of U.S. Forest Service, Forest Inventory and Analysis plot data on the Kenai Peninsula from pre- (1987) and post- (2000) spruce beetle epidemic FIA inventories (Boucher and Mead 2006). Their analysis assessed the overall pattern of vegetation change resulting from the 15-year spruce beetle epidemic and also evaluated the effect of vegetation change on forest regeneration.

Other topics of interest include:the effects of harvest and stand age on arthropod diversity and abundance (Schowalter, 1995); the importance of wildlife in controlling forest insect populations (Fayt 2004, Fayt et al 2005 – see Section 6); the ephemeral damage that can occur from seed and cone insects (Hedlin 1973; Sweeney and Turgeona 1994; Tripp and Hedlin 1956; Werner 1964); damage from sawflies (Connor et al. 1982; Morse and Kulman 1983, Popp et al. 1986), leafminers (Wagner et al. 2008), leaf skeletonizers (Friend 1927), budworms (Boulanger and Arseneault 2004) and other forest tree defoliators (e.g. Burnside and Buchholdt, 2007; Burnside et al. 2013; Wagner and Doak 2013); and a variety of other insect and disease species that can negatively impact tree productivity and regeneration potential in Alaska's boreal forests (Brewer at al. 1985; Fogal and Larocque 1992; Werner, Raffa and Illman 2006). In particular, *Tomentosus* root disease is a common disease of spruce in Alaska and neighboring Canada, where silvicultural recommendations have been developed to address stands infected by it (Lewis and Hansen 1991; Lewis, Thompson, and Trummer 2005; Reich et al. 2013; Yukon Energy, Mines, and Resources, 2014).

The effects of predicted climate change on the health and reproduction of forest in Alaska also have potential impacts for outbreaks of forest insects and diseases. Readers are directed to references in Section 9 of this bibliography: "Climate Change and Assisted Migration" (specifically: Berg et al. 2009; Chapin et al. 2010; Juday et al. 2005; Juday, Grant, and Spencer 2012, Wolken et al. 2011; Wolken and Hollingsworth 2012).

Perhaps the greatest risk from insects or disease to Alaska's forests is the potential that an exotic, invasive species might become established. In other parts of North America, examples of exotic species having widespread and significant impacts on reforestation efforts include the emerald ash borer and Dutch elm disease. A comprehensive review of exotic forest pests and their likelihood of establishment in 3,000 urban areas of the continental U.S. was published by Koch et al. (2011). Among the potential pathways for introduction, a viable mechanism for the transport of insects in Alaska could be in something as simple as commercial firewood (Jacobi et al. 2012)) or nursery stock, which is believed to be the source of the non-native Sitka spruce weevil, detected and eradicated in Anchorage during the mid-1990's (Holsten 1997). Significant efforts on the local and national level have focused on modeling and predicting the risk of exotic insect and disease, and may be of interest to forest managers in Alaska (e.g. Koch et al. 2009 and 2011; Margarey et al. 2007; Yemshanov et al. 2010a; Yemshanov et al. 2010b).

REFERENCES

◆ **Allen, J.L., Wesser, S., Markon, C.J., Winterberger, K.C., 2006.** Stand and landscape level effects of a major outbreak of spruce beetles on forest vegetation in the Copper River Basin, Alaska. For. Ecol. Manage. 227, 257-266.

Author abstract. From 1989 to 2003, a widespread outbreak of spruce beetles (Dendroctonus rufipennis) in the Copper River Basin, Alaska, infested over 275,000 ha of forests in the region. During 1997 and 1998, we measured forest vegetation structure and composition on one hundred and thirty-six 20-m x 20-m plots to assess both the immediate stand and landscape level effects of the spruce beetle infestation. A photo-interpreted vegetation and infestation map was produced using color-infrared aerial photography at a scale of 1:40,000. We used linear regression to quantify the effects of the outbreak on forest structure and composition. White spruce (Picea glauca) canopy cover and basal area of medium-to-large trees [>= 15 cm diameter-at-breast height (1.3 m, dbh)] were reduced linearly as the number of trees attacked by spruce beetles increased. Black spruce (Picea mariana) and small diameter white spruce (< 15 cm dbh) were infrequently attacked and killed by spruce beetles. This selective attack of mature white spruce reduced structural complexity of stands to earlier stages of succession and caused mixed tree species stands to lose their white spruce and become more homogeneous in overstory composition. Using the resulting regressions, we developed a transition matrix to describe changes in vegetation types under varying levels of spruce beetle infestations, and applied the model to the vegetation map. Prior to the outbreak, our study area was composed primarily of stands of mixed white and black spruce (29% of area) and pure white spruce (25%). However, the selective attack on white spruce caused many of these stands to transition to black spruce dominated stands (73% increase in area) or shrublands (26% increase in area). The post-infestation landscape was thereby composed of more even distributions of shrubland and white, black, and mixed spruce communities (17-22% of study area). Changes in the cover and composition of understory vegetation were less evident in this study. However, stands with the highest mortality due to spruce beetles had the lowest densities of white spruce seedlings suggesting a longer forest regeneration time without an increase in seedling germination, growth, or survival.

◆**Beckwith, R.C., Wolff, J.O. and J.C. Zasada**. **1977**. Bark Beetle Response to Clearcut and Shelterwood Systems in Interior Alaska Following Whole Tree Logging. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. Portland, Oregon. Research Note PNW-287. 7 p.

Author Abstract: After logging, adult beetle populations declined in clearcuts; adults increased dramatically in the 1st year and declined the 2nd year in shelterwoods. The spruce beetle does not appear to be a major threat after whole tree logging under conditions of the study.

◆ **Berg, E., J. D. Henry, C. Fastie, A. De Volder, and S. Matsuoka. 2006b**. Spruce beetle outbreaks on the Kenai Peninsula, Alaska, and Kluane National Park and Reserve, Yukon Territory: Relationship to summer temperatures and regional differences in disturbance regimes. Forest Ecology and Management 227(3):219-232

Author Abstract. When spruce beetles (Dendroctonus rufipennis) thin a forest canopy, surviving trees grow more rapidly for decades until the canopy closes and growth is suppressed through competition. We used measurements of tree rings to detect such growth releases and reconstruct the history of spruce beetle outbreaks at 23 mature spruce (Picea spp.) forests on and near the Kenai Peninsula, Alaska and four mature white spruce (Picea glauca) forests in Kluane National Park and Reserve, Yukon Territory. On the Kenai Peninsula, all stands showed evidence of 1–5 thinning events with thinning occurring across several stands during the 1810s, 1850s, 1870–1880s, 1910s, and 1970–1980s, which we interpreted as regional spruce beetle outbreaks. However, in the Kluane region we only found evidence of substantial thinning in one stand from 1934 to 1942 and thinning was only detected across stands during this same time period. Over the last 250 years, spruce beetle outbreaks therefore occurred commonly among spruce forests on the Kenai Peninsula, at a mean return interval of 52 years, and rarely among spruce forests in the Kluane region where cold winter temperatures and fire appear to more strongly regulate spruce beetle population size. The massive 1990s outbreaks witnessed in both regions appeared to be related to extremely high summer temperatures. Recent outbreaks on the Kenai Peninsula (1971–1996) were positively associated with the 5-year backwards running average of summer temperature. We suggest that warm temperature influences spruce beetle population size through a combination of increased overwinter survival, a doubling of the maturation rate from 2 years to 1 year, and regional drought-induced stress of mature host trees. However, this relationship decoupled after 1996, presumably because spruce beetles had killed most of the susceptible mature spruce in the region. Thus sufficient numbers of mature spruce are needed in order for warm summer temperatures to trigger outbreaks on a regional scale. Following the sequential and large outbreaks of the 1850s, 1870–1880s, and 1910s, spruce beetle outbreaks did not occur widely again until the 1970s. This suggests that it may take decades before spruce forests on the Kenai Peninsula mature following the 1990s outbreak and again become susceptible to another large spruce beetle outbreak. However, if the recent warming trend continues, endemic levels of spruce beetles will likely be high enough to perennially thin the forests as soon as the trees reach susceptible size.

◆ **Boggs K. , M. Sturdy, D.J. Rinella, M.J. Rinella. 2008.** White spruce regeneration following a major spruce beetle outbreak in forests on the Kenai Peninsula, Alaska. Forest Ecology and Management 255 (2008) 3571–3579

Author abstract. Between 1987 and 2000, a spruce beetle (Dendroctonus rufipennis) outbreak infested 1.19 million ha of spruce (Picea spp.) forests in Alaska, killing most of the large diameter trees. We evaluated whether these forests would recover to their pre-outbreak density, and determined the site conditions on which spruce germinated and survived following the

spruce beetle outbreak in forests of the Anchor River watershed, Kenai Peninsula, Alaska. White spruce (Picea glauca) and Lutz's spruce (Picea lutzii), a hybrid between white and Sitka spruce (Picea sitchensis), dominate the study area. We measured the pre- and post-outbreak density of spruce in 108 3 m x 80 m plots across the study area by recording all live trees and all dead trees >1.5 m tall in each plot. To determine the fine scale site conditions on which spruce germinated and survived, we measured ground surface and substrate characteristics within 20 cm circular plots around a subset of post-outbreak spruce seedlings. The density of post-outbreak spruce (855/ha) was adequate to restock the stands to their pre-outbreak densities (643/ha) for trees >1.5 m tall. We could not accurately estimate recovery for pre-outbreak spruce seedlings because dead seedlings may have decayed in the 5–18 years since the beetle
outbreak occurred. At the fine scale, spruce that germinated post-outbreak grew on a wide variety of substrates including downed log, stump, mesic organic mat, peat, hummocks and mineral soil. They exhibited a strong preference for downed logs (53%) and stumps (4%), and most (91%) of the downed logs and stumps that spruce rooted on were heavily decayed. This preference for heavily decayed logs and stumps was especially evident given that their combined mean cover was only 2% in the 3 m _ 80 m plots. Within the 3 m _ 80 m plots, spruce seedling survival was negatively correlated with bluejoint (Calamagrostis canadensis) litter cover.

◆ **Boucher, T.V. and B.R. Mead. 2006.** Vegetation change and forest regeneration on the Kenai Peninsula, Alaska following a spruce beetle outbreak, 1987–2000. For. Ecol. Manage. 227, 233-246.

Author abstract. Forests of the Kenai Peninsula, Alaska experienced widespread spruce (Picea spp.) mortality during a massive spruce beetle (Dendroctonus rufipennis) infestation over a 15-year period. In 1987, and again in 2000, the U.S. Forest Service, Pacific Northwest Research Station, Forest Inventory and Analysis Program conducted initial and remeasurement inventories of forest vegetation to assess the broad-scale impacts of this infestation. Analysis of vegetation composition was conducted with indirect gradient analysis using nonmetric multidimensional scaling to determine the overall pattern of vegetation change resulting from the infestation and to evaluate the effect of vegetation change on forest regeneration. For the latter we specifically assessed the impact of the grass bluejoint (Calamagrostis canadensis) on white spruce (Picea glauca) and paper birch (Betula papyrifera) regeneration. Changes in vegetation composition varied both in magnitude and direction among geographic regions of the Kenai Peninsula. Forests of the southern Kenai Lowland showed the most marked change in composition indicated by relatively large distances between 1987 and 2000 measurements in ordination space. Specific changes included high white spruce mortality (87% reduction in basal area of white spruce > 12.7 cm diameter-at-breast height (dbh)) and increased cover of early successional species such as bluejoint and fireweed (Chamerion angustifolium). Forests of the Kenai Mountains showed a different directional change in composition characterized by moderate white spruce mortality (46% reduction) and increased cover of late-successional mountain hemlock (Tsuga mertensiana). Forests of the Gulf Coast and northern Kenai Lowland had lower levels of spruce mortality (22% reduction of Sitka spruce (Picea sitchensis) and 28% reduction of white spruce, respectively) and did not show consistent directional changes in vegetation composition. Bluejoint increased by >= 10% in cover on 12 of 33 vegetation plots on the southern Kenai Lowland but did not increase by these amounts on the 82 plots sampled elsewhere on the Kenai Peninsula. Across the Kenai Lowland, however, regeneration of white spruce and paper birch did not change in response to the outbreak or related increases in bluejoint cover from 1987 to 2000. Although some infested areas will be slow to reforest owing to few trees and no seedlings, we found no evidence of widespread reductions in regeneration following the massive spruce beetle infestation.

◆**Boulanger, Y., and D. Arseneault. 2004**. Spruce budworm outbreaks in eastern Quebec over the last 450 years. *Canadian Journal of Forest Research* 34: 1035-1043.

Author Abstract: In this study we used dendrochronology to reconstruct the history of eastern spruce budworm (*Choristoneura fumiferana* (Clem.)) outbreaks over the last 450 years in the Bas-Saint-Laurent region of southeastern Quebec. In total, 260 tree cores were sampled from 204 beams in seven historic buildings and 12 trees in a virgin forest stand. Eight previously documented outbreaks (1975–1992, 1947–1958, 1914–1923, 1868–1882, 1832–1845, 1805–1812, 1752–1776, 1710–1724) and three presumed previous outbreaks (1678–1690, 1642–1648, 1577–1600) were identified based on periods of growth reduction. Of these 11 confirmed or presumed outbreaks, six were documented for the first time in eastern Quebec. Such data suggest that outbreak frequency has remained quite stable, with a mean interval of about 40 years between the midpoint of successive outbreaks since the mid-16th century. In addition, together with previous studies, our results indicate a strong spatial synchrony of spruce budworm outbreaks across central and eastern Quebec during the last 300 years. Consequently, our study does not support the hypothesis that spruce budworm outbreak frequency and synchrony increased during the 20th century.

◆**Brewer, J. W., J.L. Capinera, R.E. Deshon, and M.L. Walmsley. 1985**. Influence of Foliar Nitrogen Levels on Survival, Development, and Reproduction of Western Spruce Budworm, *Choristoneura occidentals* (Lepidoptera:Tortricidae). *The Canadian Entomologist* 117: 23-32.

Author Abstract: The influence of nitrogen levels in foliage of white-fir, *Abies concolor*, and Douglas-fir, *Pseudotsuga menziesii*, seedlings on various biological characteristics of the western spruce budworm, *Choristoneura occidentalis* Freeman, was studied. Seedlings were grown under greenhouse conditions and provided with nutrient solutions to maintain five foliar nitrogen levels ranging from 1.29 to 4.42% dry weight for white fir and 1.43 to 3.94% for Douglas fir. Larvae confined to treated seedlings were monitored through the next generation. Larval mortality was higher, and development time longer, at both upper and lower extremes of foliar nitrogen than at mid-level. Mean pupal weight was significantly greater for larvae reared on white fir with the mid-range foliar-nitrogen level. Mean number, and weight, of eggs laid were highest when larvae fed on foliage from the mid-range nitrogen level. Total number of larvae produced was lowest at the high and low extremes of foliar nitrogen levels.

◆**Burnside, R.E. 1991.** Falls Creek Trap Tree Sampling Study-September 16-17, 1991. State of Alaska, Dept. of Natural Resources, Division of Forestry File No. 9-3185. 10 p.

Author Abstract: A sampling study was initiated in 1991 in an area near Clam Gulch on the Kenai Peninsula to determine relative numbers of spruce beetle present in down spruce trees. The figures included demonstrate the potential for downed spruce to attract spruce beetles and enhance brood development compared to standing live trees. It also demonstrates the

effectiveness of trap trees as a management tool to suppress beetle populations and as a management strategy to beetle-proof stands with endemic beetle populations.

◆**Burnside, R., and H. Buchholdt**. **2007**. Effects of spruce budworm defolitation on spruce regeneration in Interior Alaska. Alaska Division of Forestry Annual Report. Pg 35.

Compiler Abstract: This report discusses the results and implications of several Division of Forestry projects looking at the effects of spruce budworm, larch sawfly, and larch beetle on forest productivity and regeneration.

◆**Burnside, R. E., E. H. Holsten, C. J. Fettig, J. J. Kruse, M. E. Schultz, C. J. Hayes, A. D. Graves, and S. J. Seybold**. **2011**. The northern spruce engraver, *Ips perturbatus*. FIDL 180. U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Portland, OR, 12 p.

Author abstract: Forest insect and disease leaflet (FIDL) describing the historical range, resource impacts, life cycle and biology of the northern spruce engraver, *Ips perturbatus* (Eichhoff) in North America. Information is provided on identification, evidence of infestation, associated insects and management recommendations. *I. perturbatus* is a significant tree-killing bark beetle in the boreal and sub-boreal forests of North America. Its range generally coincides with that of its primary host, white spruce, *Picea glauca*. Other hosts include Engelmann spruce, *P. engelmannii*, Lutz spruce, *P.* × *lutzii*, and in rare cases, black spruce, *P. mariana*, or Sitka spruce, *P. sitchensis*. This beetle has been recorded from Alaska, Maine, Michigan, Minnesota, Montana, Washington, and nearly all of the Canadian provinces.

◆**Burnside, R., and G. Mahal**. **2003**. Preliminary Report on the 2003 Tanacross *Ips* Trapout Project. Office Report. 3 p.

Author Abstract: This office report describes efforts by the State Division of Forestry, U.S. Forest Service, and the Tanana Chiefs Conference to trap out a building population of *Ips perturbatus* in a thinned spruce stand near Tanacross, Alaska. Initial results suggest that the program was at least initially successful in reducing overall levels of new attacks.

◆**Burnside, R., M. Schultz, N. Lisuzzo and J. Kruse. 2013.** (Final). Chapter 14. Assessing Mortality and Regeneration of Larch (*Larix laricina*) after a Landscape Level Outbreak of the Larch Sawfly (*Pristiphora erichsonii*) in Alaska (Evaluation Monitoring Project WC-EM-08-03). Pp 143-150 In: K.M. Potter and B.L. Conkling (authors), Forest Health Monitoring: National Trends, Status, and Analysis 2010. Gen. Tech. Rep. SRS-GTR-176. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 164 p. http://www.srs.fs.usda.gov/pubs/43897

Author abstract: The annual national report of the Forest Health Monitoring Program of the Forest Service, U.S. Department of Agriculture, presents forest health status and trends from a national or multi-State regional perspective using a variety of sources, introduces new techniques for analyzing forest health data, and summarizes results of recently completed Evaluation onitoring projects funded through the national Forest Health Monitoring Program. In this 10th edition in the annual series of national reports, survey data are used to identify geographic

patterns of insect and disease activity. Satellite data are employed to detect geographic clusters of forest fire occurrence. Data collected by the Forest Inventory and Analysis Program of the Forest Service are employed to detect regional differences in tree mortality. Established forest fragmentation assessment protocols are used to characterize and compare the fragmentation of landcover types nationally. A new methodology for the comparison of moisture conditions among different geographical areas and time periods is described. Forest Inventory and Analysis data are used to conduct an empirical assessment of the Nation's standing dead tree resources. The potential impacts of climate change on forest soil critical acid load limits are explored. Seven recently completed Evaluation Monitoring projects are summarized, addressing forest health concerns at smaller scales.

◆ **Connor, M.D., Houseweart, M.W., and H. M. Kulman**. **1982**. Susceptibility of White Spruce Seed Sources to Yellow-headed Spruce Sawfly, *Pikonema alaskensis*, (Hymenoptera:Tenthredinidae). The Great Lakes Entomologist, 15:207-211.

Author Abstract: A field caging technique was used to test the susceptibility of 25 white spruce, *Picea glauca* (Moench) Voss, seed sources to attack by *Pikonema alaskensis* (Rohwer). No significant differences were found in the number of eggs laid, number of dessicated eggs, or number of egg slits. Percent oviposition differed significantly within a tree, the south side having more eggs. Bud size differed significantly within trees and between trees but not between seed sources. The number of sawfly eggs laid on a bud could not be related to bud size. There was no significant difference in susceptibility of the seed sources studied to *Pikonema alaskensis*.

◆ **Fettig, C. J., R. E. Burnside, C. J. Hayes, J. J. Kruse, N. J. Lisuzzo, S. R. McKelvey, S. R. Mori, S. K. Nickel, and M. E. Schultz**. **2013**. Factors influencing northern spruce engraver colonization of white spruce slash in interior Alaska. Forest Ecology and Management 289:58–68.

Author abstract: The northern spruce engraver, *Ips perturbatus* (Eichhoff), is a significant tree-killing bark beetle in the boreal and sub-boreal forests of North America. Its range generally coincides with that of its primary host, white spruce, *Picea glauca*. Other hosts include Engelmann spruce, *P. engelmannii*, Lutz spruce, *P.* × *lutzii*, and in rare cases, black spruce, *P. mariana*, or Sitka spruce, *P. sitchensis*. Outbreaks of *I. perturbatus* in interior Alaska are most frequently associated with forest disturbances and logging debris. When favorable climatic conditions coincide with large quantities of suitable host material, *I. perturbatus* populations may erupt, resulting in the mortality of apparently-healthy trees over extensive areas. We review the ecology and management of *I. perturbatus*, a species that appears to be increasing in pest status as a result of recent climatic changes. Furthermore, we describe three years of work conducted to identify effective silvicultural- and, to a lesser extent, semiochemical-based management strategies. We concentrate on the effects of commonly used slash management practices on *I. perturbatus* performance in slash, and on the effectiveness of these practices for minimizing associated levels of tree mortality in residual stands. Finally, we provide recommendations for best management practices based on our research.

◆ **Flint, C.G. 2007.** Changing Forest Disturbance Regimes and Risk Perceptions in Homer, Alaska. Risk Analysis 27(6): 1597-1608.

Author abstract. Forest disturbances caused by insects can lead to other disturbances, risks, and changes across landscapes. Evaluating the human dimensions of such disturbances furthers understanding of integrated changes in natural and social systems. This article examines the effects of changing forest disturbance regimes on local risk perceptions and attitudes in Homer, Alaska. Homer experienced a spruce bark beetle (*Dendroctonus rufipennis*) outbreak with large-scale tree mortality and a 5,000-acre fire in 2005. Qualitative interviews and quantitative analysis of mail surveys are used to examine community risk perception and relationships with land managers pre- and post-fire. Results show a decrease in the saliency of the spruce bark beetle as a community issue, a coalescence of community risk perceptions about fire, and conflicting findings about satisfaction with land managers and its relationship with risk perception.

◆**Flint, C.G. 2006**. Community perspectives on spruce beetle impacts on the Kenai Peninsula, Alaska. For. Ecol. Manage. 227(3): 207-218.

Author abstract: A recent outbreak of spruce beetles (*Dendroctonus rufipennis*) in forests on the Kenai Peninsula, Alaska was met with substantial variation in response among people and communities situated within this changing landscape. Interviews and mail surveys administered to residents in six Kenai Peninsula communities revealed differences in perception of biophysical, social, and economic impacts that resulted from changing forest conditions related to the spruce beetle outbreak. Together, the qualitative and quantitative data provided evidence of collective experience and community risk perception across Kenai Peninsula communities. Fire, falling trees, declining quality of watersheds and wildlife habitat, economic fluctuations, landscape change, and emotional loss were some of the issues faced. In some communities, increased timber harvesting brought short- term, positive economic change in the wake of the spruce beetle outbreak. In other communities, the loss of a living spruce (*Picea* spp.) forest profoundly affected quality of life, and led to community conflict, increased risk perception of future impacts, and economic challenges. Biophysical changes were keenly felt by many residents. Communities at different stages in the spruce beetle outbreak revealed temporal and spatial variations in perceived impacts. The diverse array of perceived impacts and risks from the spruce beetle outbreak in Kenai Peninsula communities presents both opportunities and obstacles for forest management in the context of changing forest conditions.

◆**Fogal, W.H. and G. Larocque. 1992**. Development of flowers, cones, and seeds in relation to insect damage in two white spruce communities. *For. Ecol. Manage.,* 47: 335-348.

Author Abstract: Seasonal development of white spruce *(Picea glauca* (Moench) Voss flowers, cones, and seeds was examined in relation to the onset of damage by insects. In addition, damage to cones and seeds by insects and seed losses to abortion were examined at several sampling dates in two types of tree communities; older, widely-spaced trees on farmlands and younger closely-spaced trees in plantations. Insect damage to cones and seeds was evident shortly after cones turned from an upright to a pendent position. Damage to cones reached a maximum in mid-June for most insects and early or mid-July for others. The number of sound seeds decreased steadily during the summer, reaching a minimum by mid-July. At the final sampling date, the number of sound seeds was larger in farmland trees. In farmland trees 16% of seeds developed to the mature embryo stage, 30% aborted before or during the embryo stage, 23% were lost to insects, and 32% of losses could not be identified. The respective statistics for plantation trees were 9%, 24%, 29%, and 35%. Damage by the spruce budworm *Choristoneura fumiferana* (Clem.) and spruce seedmoth *Cydia strobilella* (L.) was greater in farmland trees compared to plantations, and for spruce cone maggot *Strobilomyia neanthracina* Michelsen, damage was higher in plantations for two sampling dates. Information on temporal changes in the onset of damage by insects and loss of seeds can be used as guides for timing insect control and cone collection operations; differences between communities suggest that tree community characteristics should be considered in managing seed crops.

◆**Friend, R.B. 1927**. The Biology of the Birch Leaf Skeletonizer, *Bucculatrix canadensisella*, Chambers. Connecticut Agricultural Experiment Station Bulletin 288:395-488.

Author Abstract: The biology of *Bucculatrix canadensisella*, or, as it is more commonly called, the birch leaf skeletonizer, is known to only a very slight extent. Not only does the insect have peculiar habits and a specific structure, but its great abundance during certain years, coupled with its habit of feeding on native birches, renders it of interest economically as well as biologically. In the following pages are the results of investigations, made during the years 1924, 1925, and 1926, into its habits, reactions, distribution, history, and morphology. The work is not complete, but it is intended that the gaps shall be filled, in part at least, in the future.

◆**Goodman, L.F. and B.A. Hungate**. **2006.** Managing forests infested by spruce beetles in south-central Alaska: Effects on nitrogen availability, understory biomass, and spruce regeneration. For. Ecol. Manage. 227(3): 267-274.

Author abstract: In Alaska, an outbreak of spruce beetles (*Dendroctonus rufipennis*) recently infested over one million hectares of spruce (*Picea* spp.) forest. As a result, land management agencies have applied different treatments to infested forests to minimize fire hazard and economic loss and facilitate forest regeneration. In this study we investigated the effects of high-intensity burning, whole-tree harvest, whole-tree harvest with nitrogen (N) fertilization, and conventional harvest of beetle-killed stands 4 years after treatment, as well as clear-cut salvage harvest 6 years after treatment. We measured available soil ammonium and nitrate and estimated N loss from leaching using in situ cation and anion resin exchange capsules. We also assessed spruce regeneration and responses of understory plant species. Availability and losses of N did not differ among any of the management treatments. Even a substantial application of N fertilizer had no effect on N availability. Spruce regeneration significantly increased after high- intensity prescribed burning, with the number of seedlings averaging 8.9 m^{-2} in burn plots, as compared to 0.1 m^{-2} in plots that did not receive treatment. Biomass of the pervasive grass bluejoint (*Calamagrostis canadensis*) was significantly reduced by burning, with burn plots having 9.5% of the *C. canadensis* biomass of plots that did not receive treatment. N fertilization doubled *C. canadensis* biomass, suggesting that N fertilization without accompanying measures to control *C. canadensis* is the least viable method for promoting rapid spruce regeneration.

◆**Hard, J.S. and E.H. Holsten**. **1985**. Managing White and Lutz Spruce Stands in South-central Alaska for Increased Resistance to Spruce Beetle. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. Portland, Oregon. General Technical Report PNW-188. 21 p.

Author Abstract: Thinning is recommended for maintaining vigorous tree growth to minimize losses caused by spruce beetles and windthrow in residual stands of spruce in southcentral Alaska. The anatomy of conifer stems, the variation in stem diameter growth, and the variability of tree response to wounding are discussed to explain why trees become vulnerable to attack by bark beetles. A working hypothesis is presented as a rationale for maintaining vigorous tree growth.

◆**Hedlin, A. F**. **1973**. Spruce Cone Insects in British Columbia and Their Control. The Canadian Entomologist, 105:133-122.

Author Abstract: Insects cause considerable loss of seed in white spruce, *Picea glauca* (Moench) Voss, and Engelmann spruce, *P. engelmannii* Parry, in British Columbia. The most important species are a maggot, *Hylemya anthracina* (Cz.), and a seed moth, *Laspeyresia youngana* (Kit.). Other insects are: a seed chalcid, *Megastigmus piceae* Roh., a cone axis midge, *Dasineura rachiphaga* Tripp, a gall midge, *D. canadensis* Felt, a seed midge, *Mayetiola carpophaga* Tripp, and a scale-feeding midge. These insects also occur in cones of Sitka spruce, *P. sitchensis* (Bong.) Carr., and black spruce, *P. mariana* (Mill.) BSP. The systemic insecticides dimethoate and formothion proved to be effective against these insects when applied as sprays following pollination in mid-June.

◆**Holsten**, **E.H**. **1998**. *Ips perturbatus*; A Pest of Managed Stands? 1998 Update. USDA Forest Service. Alaska Region, Forest Health Protection Biological Evaluation R10-TP-77, November 1998. 9 p.

Author Abstract: An average of only 3.6% of the live residual spruce were successfully attacked and killed in 1998 as compared to 32% in 1997 and 11% in 1996. Thus, a total of 47% of the residual spruce in the Granite Creek thinned areas were killed in a three-year period.

◆**Holsten, E. 1997.** Sitka Spruce Weevil (Coleo: Curculionidae; Pissodes strobe Hopk.) A Risk to Ornamental and Native Spruce in South-Central Alaska?? A note from the 16th Alaska Greenhouse and Nursey Conference Feb. 20-21, Soldotna, AK.

Compiler Abstract. This note briefly discusses the discovery of *Pissodes strobe* on outplanted nursery stock in Anchorage in 1994-1996. It goes on to discuss the threat posed by *P. strobe,* a major pest of spruce and pine trees in the lower 48 and Canada, but absent in Alaska. Based on the information in this report, it appears the USDA Forest Service, and University of Alaska Cooperative Extension Service personnel assisted in the eradication of infested material.

◆**Holsten, E.H**. **1994**. Suitability of Powerline Right-of-Way Clearing Debris as Breeding Material for Spruce Bark Beetles. USDA Forest Service, Alaska Region, Forest Health Management, Anchorage, Alaska. Tech. Report R10-TP-49. 6 p.

Compiler Abstract: Based on the results from this study, it appears that limbed and bucked logs, if not attacked during the first spruce beetle dispersal flight, are significantly less productive as breeding material if attacked the second flight season. There appears no reason to check scattered right-of-way clearing debris more than once. If this material is yarded along the shaded edges of a ROW clearing, it could then remain attractive for two years. However, this material appears to remain attractive and productive as breeding material for *Ips* beetles. The risk of *Ips*-caused mortality, however is much less than that of spruce beetle.

◆**Holsten, E.H. 1990**. Spruce Beetle Activity in Alaska: 1920-1989. USDA For. Serv., Alaska Region Tech. Rpt. R10-90-18. 28p.

Author Note: An interesting finding from this review of Alaska spruce beetle infestations is that many areas have been repeatedly infested over the years: Eklutna (1950s & 1980s); Tlikakila River (1950s & 1980s); Resurrection Creek (1957 & 1977), Skwentna River (1930s & 1989), Willow Creek (1930s & 1980s); Tustumena Lake (1950s & 1980s); and most of the northern portion of the Kenai National Wildlife Refuge, to name a few. The general result of the early infestations was a reduction in the size of the residual stems because the majority (up to 90%) of all stems greater than 6” in dbh were killed by spruce beetles. Type conversion did not occur in many areas because there were plenty of small spruce remaining (Beckwith and Curtis 1972). It appears that these stands of small spruce became overstocked and less thrifty with age and again became susceptible to spruce beetle outbreaks. Many of the repeatedly infested areas are undergoing a type conversion as little or no natural spruce regeneration is present. In order to bring these sites back into spruce, some site preparation such as brought about by fire or logging must be undertaken followed by planting. Type conversion has also occurred in mixed hardwood/spruce stands that have been infested. For example, the severe spruce beetle infestation near Tyonek in the 1970s resulted in 65% mortality of all spruce over 5” dbh. Birch became the dominant species in the residual stands (Baker and Kemperman 1974).

◆ **Holsten, E.H., R.A. Werner, and R.L. DeVelice. 1995.** Effects of a spruce beetle (Coleoptera:Scolytidae) outbreak and fire on Lutz spruce in Alaska. Environmental Entomology 24(6):1539-1547.

Author abstract. The spruce beetle, Dendroctonus rufipennis (Kirby), has had a major effect on the spruce forests of southcentral Alaska. In one area of the Chugach National Forest, 51% of the Lutz spruce, Picea glauca x lutzii Little, or nearly 90% of the commercial stand volume was killed by spruce beetles during a 16-yr period. The majority of the tree losses occurred during the first 10 yr of the outbreak. Tree species composition remained essentially the same after the outbreak. Forest structure changed with decreased tree density, and species richness declined significantly on the unburned, spruce beetle-effected plots. This reduction in plant diversity was probably a result of the significant increase, and competitive advantage, of bluejoint grass, Calamagrostis canadensis (Michaux) Beauvois, and fireweed, Epilobium angustifolium L., in the heavily beetle-effected plots. Although species richness did not change 7 yr after a prescribed fire, species composition did change. Specifically, the occurrence and percentage of bluejoint and fireweed cover significantly increased.

◆**Holsten, E.H., Zogas, K., Werner, R.A. and R.L. Wolfe**. **1979**. Resurrection Creek Spruce Beetle Infestation; A Three-Year Interim Report. USDA Forest Service, Alaska Region, State & Private Forestry. Technical Report R10-1-79. 19 p.

Author Abstract: The pre-outbreak volume loss of spruce was only 44% of the volume lost during the 1976-1978 period. Total mortality throughout the permanent plots was 163 trees over three years with only 13% due to causes other than spruce beetle. The prediction was made that the spruce beetle population is static to declining.

◆**Jacobi, W. R., Hardin, J. G., Goodrich, B. A., and C. M. Cleaver. 2012**. Retail Firewood Can Transport Live Tree Pests. Journal of Economic Entomology 105(5):1645-1658.
Author Abstract: Untreated firewood can harbor destructive insects and pathogens and transport them to uninfested areas. In a national survey of retail locations selling firewood in 18 states, over half (52%) of the firewood was from sources out of the purchase state and 50% showed evidence of insect infestation. In a three state survey of southern Rocky Mountain retailers, the most common retailer types carrying firewood were grocery stores and department or big box stores followed by gas stations or convenience stores. In 2007–2009, we purchased 419 firewood bundles from retailers in Colorado, New Mexico, Utah, and Wyoming and caged the firewood to quantify insect emergence. Live insects emerged from 47% of firewood bundles over 18 mo of rearing time. Approximately 11 insects emerged on average from each infested bundle (1–520 per bundle). Pine, fir, and mixed-conifer bundles yielded the greatest number of insects. Beetles (Coleoptera) were prominent and made up the majority of individuals (3–60 individuals in each of 24 families). Most Coleoptera were bark and ambrosia beetles (subfamily Scolytinae) while wood borers (Buprestidae, Cerambycidae, Siricidae) occurred in lower numbers. Firewood with evidence of previous or current insect infestation was more likely to have insects emerge than firewood without such evidence. The risk of moving live native or nonindigenous insects in untreated firewood is high because insects emerged up to 558 d from purchase date. Retail firewood should be heat treated in a manner to eliminate insects that is uniformly accepted across North America.

◆**Koch, F., Yemshanov, D., McKenney, D.W., and W. D. Smith. 2009**. Evaluating Critical Uncertainty Thresholds in a Spatial Model of Forest Pest Invasion Risk. Risk Analysis, Vol. 29, No. 9, 2009 DOI: 10.1111/j.1539-6924.2009.01251.x

Author abstract: Pest risk maps can provide useful decision support in invasive species management, but most do not adequately consider the uncertainty associated with predicted risk values. This study explores how increased uncertainty in a risk model's numeric assumptions might affect the resultant risk map. We used a spatial stochastic model, integrating components for entry, establishment, and spread, to estimate the risks of invasion and their variation across a two-dimensional landscape for *Sirex noctilio*, a nonnative woodwasp recently detected in the United States and Canada. Here, we present a sensitivity analysis of the mapped risk estimates to variation in key model parameters. The tested parameter values were sampled from symmetric uniform distributions defined by a series of nested bounds (±5%, … , ±40%) around the parameters' initial values. The results suggest that the maximum annual spread distance, which governs long-distance dispersal, was by far the most sensitive parameter. At ±15% or larger variability bound increments for this parameter, there were noteworthy shifts in map risk values, but no other parameter had a major effect, even at wider bounds of variation. The methodology presented here is generic and can be used to assess the impact of uncertainties on the stability of pest risk maps as well as to identify geographic areas for which management decisions can be made confidently, regardless of uncertainty.

◆**Koch, F.H., Yemshanov, D., Colunga-Garcia, M., Magarey, R.D., and Smith, W.D. 2011**. Potential establishment of alien-invasive forest insect species in the United States: where and how many? Biological Invasions. 13: 969-985.

Author abstract: International trade is widely acknowledged as a conduit for movement of invasive species, but few studies have directly quantified the invasion risk confronting individual locations of interest. This study presents estimates of the likelihood of successful entry for alien forest insect species at more than 3,000 urban areas in the contiguous United States (US). To develop these location-specific estimates, we first utilized historical merchandise imports and insect incursions data to estimate an annual US rate of alien insect species establishment. Next, we used historical pest interception data to calculate the proportion of all insects arriving at US ports of entry that are associated with forest hosts. We then combined these results to estimate a nationwide establishment rate specifically for alien forest insects. Finally, we employed international and domestic commodity flow networks to allocate this nationwide rate to individual US urban areas. For 2010, we estimated the nationwide rate as 1.89 new alien forest insect species per year. While the establishment rates observed at most urban areas were low (<0.005 new species/year), for a few select areas the rates predict new alien forest insect species establishments every 5–15 years. This national-scale assessment provides a realistic depiction of human-assisted establishment potential in the US as well as functional inputs for quantitative models of invasion. Overall, these analyses support broad-scale biosecurity and management strategies.

◆ **Lewis, K.J., and E. M. Hansen. 1991.** Survival of *Inonotus tomentosus* in stumps and subsequent infection of young stands in north central British Columbia. Canadian Journal of Forest Research 21(7): 1049-1057.

Author abstract: Distribution of tomentosus root disease in spruce (*Picea glauca* (Moench) Voss and *P. glauca* × *engelmannii* Engelm.) and pine (*Pinus contorta* var. *latifolia* Engelm.) stumps in 1- to 30-year-old harvest units, survival of *Inonotus tomentosus* (FR) Teng in stumps, and infection of regeneration trees were examined by transect surveys and root excavations. The number of diseased stumps ranged from 8 to 71 per hectare (2.1–27.5%); these were in patches, commonly two to three stumps each. Viable mycelium was found in 80 and 53% of the 30-year-old spruce and pine stumps, respectively. Distal growth by *I. tomentosus* in roots ceased shortly after harvest. Narrow decay and stain columns were observed in 1- and 2-year-old spruce stumps. In older stumps, the fungus had colonized the sapwood and bark. In pine, colonization of the bark and cambium was common at all stump ages. Spruce stumps, with longer, horizontally oriented roots and a greater percentage of colonized roots, caused more infections of regeneration than pine stumps (14 and 5%, respectively, of the five regeneration trees closest to each stump). Regeneration trees had a 25% chance of infection if planted within 2 m of decayed spruce stumps and 0.5 m of decayed pine stumps. The probability of infection decreased to 10% at 3.75 and 2.75 m from spruce and pine stumps, respectively. Both spruce and pine regeneration were infected, often at points of disruption in the bark, such as a feeder root or root branch.

◆**Lewis, K.J., Thompson, R.D., and L. Trummer**. **2005**. Growth Response of Spruce infected by *Inonotus tomentosus* in Alaska and interactions with spruce beetle. Canadian Journal of Forest Research 35: 1455-1463.

Author Abstract: Mortality of overstory trees released surviving trees from competition, causing compensatory growth in healthy to moderately infected trees, which masked the effect of the root disease. Authors found that the magnitude of growth release was negatively related to disease severity.

◆**Magarey, R.D., Borchert, D.M., Engle, J.S., Colunga-Garcia, M., Koch, F.H. and D. Yemshanov. 2011**. Risk maps for targeting exotic plant pest detection programs in the United States. OEPP/EPPO Bulletin. 41:46-56.

Author abstract: In the United States, pest risk maps are used by the Cooperative Agricultural Pest Survey for spatial and temporal targeting of exotic plant pest detection programs. Methods are described to create standardized host distribution, climate and pathway risk maps for the top nationally ranked exotic pest targets. Two examples are provided to illustrate the risk mapping process: late wilt of corn (*Harpophora maydis*) and the giant African land snail (*Achatina fulica*). Host risk maps were made from county-level crop census and USDA Forest Inventory and Analysis data, respectively. Climate risk maps were made using the North Carolina State University–USDA APHIS Plant Pest Forecasting System (NAPPFAST), which uses a web-based graphical user interface to link climatic and geographic databases with interactive templates for biological modelling. Pathway risk maps were made using freight flow allocation data sets to move commodities from 7 world regions to 3162 US urban areas. A new aggregation technique based on the Pareto dominance principle was used to integrate maps of host abundance, climate and pathway risks into a single decision support product. The maps are publicly available online (http://www.nappfast.org). Key recommendations to improve the risk maps and their delivery systems are discussed.

◆**Matsuoka, S.M., Handel, C.M., and D.R. Ruthrauff. 2001.** Densities of breeding birds and changes in vegetation in an Alaskan boreal forest following a massive disturbance by spruce beetles. *Canadian Journal of Zoology* 79:1678-1690.

Author Abstract: We examined bird and plant communities among forest stands with different levels of spruce mortality following a large outbreak of spruce beetles (*Dendroctonus rufipennis* (Kirby)) in the Copper River Basin, Alaska. Spruce beetles avoided stands with black spruce (*Picea mariana*) and selectively killed larger diameter white spruce (*Picea glauca*), thereby altering forest structure and increasing the dominance of black spruce in the region. Alders (*Alnus* sp.) and crowberry (*Empetrum nigrum*) were more abundant in areas with heavy spruce mortality, possibly a response to the death of overstory spruce. Grasses and herbaceous plants did not proliferate as has been recorded following outbreaks in more coastal Alaskan forests. Two species closely tied to coniferous habitats, the tree-nesting Ruby-crowned Kinglet (*Regulus calendula*) and the red squirrel (*Tamiasciurus hudsonicus*), a major nest predator, were less abundant in forest stands with high spruce mortality than in low-mortality stands. Understory-nesting birds as a group were more abundant in forest stands with high levels of spruce mortality, although the response of individual bird species to tree mortality was variable. Birds breeding in stands with high spruce mortality likely benefited reproductively from lower squirrel densities and a greater abundance of shrubs to conceal nests from predators.

◆**Morse, B.W., and H. M. Kulman. 1983**. Plantation white spruce mortality: estimates based on aerial photography and analysis using a life-table format. Canadian Journal of Forest Research, 14:195-200.

Author Abstract: White spruce, *Picea glauca* (Moench) Voss, mortality was estimated in two 142-ha, 11- and 12-year-old plantations in north central Minnesota, using small-format color aerial photography at a scale of 1:9600 and groundplots. A double sample with regression sampling method determined mortality of trees 5 years after planting. The yellow-headed spruce sawfly, *Pikonema alaskensis* (Rohwer), was responsible for 65% of the mortality in the last two age intervals. Differential mortality and growth of white spruce was observed between plantations. Site preparation is suggested as a possible cause of these differences.

◆ **Packee, E.C. 1997.** Restoring spruce beetle-impacted forests in Alaska. Agroborealis 1997 29(1): 18-24.

Compiler abstract. This article reviews the ecology and impacts of spruce bark beetle *(Dendroctonus rufipennis)* in Alaskan forests, and recommends actions for restoring forests to maintain spruce and mixed stands of various ages, densities, and structures. The author emphasizes collection of local spruce seed, discourages use of non-native species, and discusses restoration actions for riparian zones.

◆**Popp, M. P., H. M. Kulman, and E. H. White**. **1986**. The effect of nitrogen fertilization of white spruce (*Picea glauca*) on the yellow-headed spruce sawfly (Pikonema alaskansis). *Canadian Journal of Forest Research* 16: 832-835.

Author Abstract: Fertilization with 224 and 448 kg Nha^{-1} applied to white spruce, *Picea glauca* (Moench) Voss, as ammonium nitrate significantly increased concentrations of foliar N. Trees with 1.10 to 1.29% foliar N on July 3 had the highest average number of yellow-headed spruce sawfly, *Pikonema alaskansis* (Rohwer), larvae per tree (final population) and the lowest percent mortality. This corresponded to trees receiving 224 kg N ha^{-1}. Although not significantly, the final population increased, and the percent mortality decreased with increasing N concentrations up to 1.29% (July 3) (N-deficient trees). As foliar N concentrations, at the time of feeding, increased above 1.29% (N-sufficient trees), final population decreased and percent mortality increased. Therefore, indiscriminate use of fertilizers may increase insect numbers.

◆ **Reich, R.W., Lewis, K.J., and A. M. Wiensczyk. 2013.** Tomentosus Root Rot Forest Health Stand Establishment Decision Aid. Extensions Note, Journal of Ecosystems & Management, 14:1 p 1-8.

Author Abstract. Tomentosus root rot (hereafter referred to as “tomentosus”) is ubiquitous in the sub-boreal and boreal spruce and pine forests of British Columbia. Caused by the fungus *Onnia tomentosa,* its widespread distribution is attributed to the organism’s ability to spread by airborne spores (Gibson 2005) and to its persistence on a site from one rotation to the next. As a result, high-risk ecosystems may sustain relatively high levels of infection. The prime host is Interior spruce species, with lodgepole pine being moderately susceptible. Other species can be affected but usually to a much lesser degree. Tomentosus can reduce productivity and harvestable yield in infected stands through mortality, growth reduction, and butt rot. Infected trees are also highly susceptible to windthrow and may be susceptible to insect damage. In young stands, it can reduce stocking 10% by the age of 20 years, although it rarely results in unacceptable stocking because of the typically scattered and light levels of infection in most stands. The purpose of this stand establishment decision aid (SEDA) is to help guide forest management in stands where tomentosus root rot is likely to be a significant issue. The following pages describe susceptible stand types, tomentosus biology, hazard ratings, forest productivity considerations, and appropriate management practices. A resource and reference list that readers can use to find more detailed information is also included.

◆ **Ross, D.W., G.E. Daterman, J.L. Boughton, and T.M. Quigley. 2001.** Forest health restoration in south-central Alaska: a problem analysis. Gen. Tech. Rep. PNW-GTR-523. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 38 p.

Author abstract. A spruce beetle outbreak of unprecedented size and intensity killed most of the spruce trees on millions of acres of forest land in south-central Alaska in the 1990s. The tree mortality is affecting every component of the ecosystem, including the socioeconomic culture dependent on the resources of these vast forests. Based on information obtained through workshops and outreach to resource managers and diverse stakeholders, we have developed priority issues for restoring the land. Wildfire is a major issue, particularly for the wildland-urban interface areas around Anchorage and on the Kenai Peninsula. The tasks of land managers are integrative and multidisciplinary and involve many science-related issues. They primarily revolve around the problem of how to reduce risk of wildfire and ensure reforestation in ways that will accommodate the needs for wildlife habitat, maintain healthy hydrologic conditions, and generally conserve ecological values for the future. The research approach outlines a "what if" scenario of management options based on levels of investment and targets for restoration. Modeling and visualization research would provide previews of future conditions based on levels of investment, selected landscapes, and the desired conditions selected among restoration options.

◆ **Schowalter, T.D. 1995.** Canopy arthropod communities in relation to forest age and alternative harvest practices in western Oregon. Forest Ecology and Management 78:115-125.

Author Abstract. Arthropod community structure and herbivory were compared in replicate Douglas-fir and western hemlock canopies in intact old-growth (> 400-year-old), and Douglas-fir only in partially harvested old-growth, natural mature (150-year-old) stand, and regenerating plantations (10–20-year-old) in a 15 000 ha area including the H.J. Andrews Experimental Forest in western Oregon. Species diversity and abundances of several taxa, especially predators and detritivores, were significantly lower in plantations compared to older forests. Mature, old-growth, and partially harvested stands showed few significant differences, but principal components analysis suggested some differences in community structure and indicated that old-growth was least variable (tighter clustering) in arthropod diversity and abundance, whereas partially harvested stands were most variable. Defoliation was higher in the mature stands, probably because these stands were composed of relatively dense and pure Douglas-fir. Although old-growth appeared to be the source of greatest arthropod biodiversity in these forests, arthropod communities in Douglas-fir canopies may largely recover old-growth structure by 150 years, and partially harvested stands retain substantially greater arthropod diversity than do regenerating plantations.

◆**Schulz, B. 2000.** Resurrection Creek Permanent Plots Revisited. USDA Forest Service, Forest Health Protection, Alaska Region, Anchorage, Alaska. Technical report R10-TP-89. 14 p.

Author Abstract: Vegetation plot data suggests that bluejoint reed grass is becoming less vigorous twenty years after initial spruce beetle outbreak. Lack of spruce in-growth in burned plots suggests that the fire destroyed most regenerating trees. Minimal numbers of spruce seedlings may be attributed to a limited seed source following the fire. Birch seedlings were found on more burned plots than unburned, reflecting species composition prior to the burn.

◆**Schulz, B**. **1996**. Response of Residual Spruce Beetle-impacted Stands in Resurrection Creek Drainage, Kenai Peninsula, Alaska. USDA Forest Service. Alaska Region. Anchorage, Alaska. Technical Report R10-TP-62. 20 p.

Author Abstract: Radial growth of trees surviving a spruce beetle outbreak was assessed for the past 35 years. Evidence of release events was apparent for 28% of the trees in spruce beetle impacted plots, and for 4% of the trees in unimpacted stands. Radial growth was decreasing prior to and increased after the beetle outbreak in both impacted and unimpacted stands.

◆**Suring, L.H, M.I. Goldstein, S. Howell, and C.S. Nations. 2006.** Effects of spruce beetle infestations on berry productivity on the Kenai Peninsula, Alaska. **Forest Ecology and Management 227(3):247-256.**

Author abstract. Understanding the dynamics of berry productivity provides significant insight for managing the landscape to maintain ecosystem functions. On the Kenai Peninsula, as many as 14 mammal and 30 bird species commonly feed on berries produced by shrubs and forbs associated with spruce forests. Brown bears (*Ursus arctos*) and black bears (*Ursus americanus*), in particular, rely on berry crops for foraging. Gathering berries for subsistence or recreation purposes is also important to local residents and visitors. Recent spruce beetle (*Dendroctonus rufipennis* Kirby) infestations on the Kenai Peninsula have altered the dynamics of berry productivity. To assess this relationship, we evaluated the number and productivity of berries with the following environmental covariates: canopy cover, overstory type, infestation level, year of infestation, land type, and land type association. Data were sufficient to describe the relationships of these variables with the productivity of bunchberry dogwood (*Cornus canadensis*), black crowberry (*Empetrum nigrum*), false toadflax (*Geocaulon lividum*), strawberryleaf raspberry (*Rubus pedatus*), lingonberry (*Vaccinium vitis-idaea*), and a combination of 24 other species. We accomplished this using log-linear regression by which we estimated the variance using the negative binomial distribution. Canopy cover significantly influenced the productivity of all berry species except for false toadflax. Increasing canopy cover had a negative effect on berry productivity except for strawberryleaf raspberry. Overstory type influenced the productivity of all individual berry species. Infestation level was significantly related to the productivity of black crowberry, false toadflax, and the combined species group. Berry counts were generally lower in plots with low or medium infestation than in plots with high infestation. Relating the dynamics of berry productivity to the effects of spruce beetle infestations provides the opportunity for better management of post-beetle-infested forests.

◆**Sweeney, J.D., and J.J. Turgeona**. **1994**. Life Cycle and Phenology of a Cone Maggot, Strobilomyia appalachensis Michelsen (Diptera: Anthomyiidae), on Black Spruce, *Picea mariana* (Mill.) B.S.P., in Eastern Canada. The Canadian Entomologist, 126:49-59.

Author Abstract: The life cycle of Strobilomyia appalachensis Michelsen, a maggot exploiting black spruce seed cones, was studied in two plantations in northern Ontario in 1987 and 1988, and two seed orchards in New Brunswick in 1991 and 1992. Oviposition by S. appalachensis occurs slightly later than the white spruce cone maggot, S. neanthracina Michelsen, relative to seed cone development; otherwise the life cycles of the two species are similar. Adults were trapped near host foliage in May and early June. Eggs were laid between the scales of seed cones during early June, starting when the scales on most cones were closed and ending 1 week after cones were fully pendant. Up to five eggs per cone were observed but single eggs were most common. The first larval molt occurred within the egg chorion and second-instar larvae emerged from the egg. Second-instar larvae were found in the cones during the 2nd and 3rd week of June, and third instars from the 3rd week of June until mid to late July. Larvae tunneled around the cone axis and destroyed an average of 60% of the total seed per cone before exiting and dropping to the soil. Larval drop occurred from late June to late July and was significantly correlated with periods of rainfall. Mature larvae moved into the duff and overwintered in the soil as pupae. Aspects of the maggot's life history are discussed in relation to pest management strategies.

◆**Tripp, H.A., and A.F. Hedlin**. **1956**. An Ecological Study and Damage Appraisal of White Spruce Cone Insects. The Forestry Chronicle, 32:400-410.

Author Abstract: This paper discusses insects which inhabit the cones of white spruce, *Picea glauca* (Moench) Voss, in Ontario and Saskatchewan. Insects which spend their entire developmental stages within the cone and cause appreciable damage are discussed at greater length. In Ontario, these are the spruce seedworm, *Laspeyresia youngana* (Kft.) and the spruce cone maggot, *Pegohylemyia anthracina* Czerny. In Saskatchewan, *L. youngana* is the main offender. Other insects which are of less economic importance from the standpoint of seed production are gall midges (cecidomyiids) and casual cone feeders.

◆**Wagner, D., DeFoliart, L., Doak, P., and J. Schneiderheinze**. **2008**. Impact of epidermal leaf mining by the aspen leaf miner (*Phyllocnistis populiella*) on the growth, physiology, and leaf longevity of quaking aspen. Oecologia, 157:259-267.

Author Abstract: The aspen leaf miner, *Phyllocnistis populiella,* feeds on the contents of epidermal cells on both top (adaxial) and bottom (abaxial) surfaces of quaking aspen leaves, leaving the photosynthetic tissue of the mesophyll intact. This type of feeding is taxonomically restricted to a small subset of leaf mining insects but can cause widespread plant damage during outbreaks. We studied the effect of epidermal mining on aspen growth and physiology during an outbreak of *P. populiella* in the boreal forest of interior Alaska. Experimental reduction of leaf miner density across two sites and 3 years significantly increased annual aspen growth rates relative to naturally mined controls. Leaf mining damage was negatively related to leaf longevity. Leaves with heavy mining damage abscised 4 weeks earlier, on average, than leaves with minimal mining damage. Mining damage to the top and bottom surfaces of leaves had different effects on physiology. Mining on the top surface of the leaf had no significant effect on photosynthesis or conductance and was unrelated to leaf stable C isotope ratio ($\delta^{13}C$). Mining damage to the bottom leaf surface, where stomata are located, had significant negative effects on net photosynthesis and water vapor conductance. Percent bottom mining was positively related to leaf $\delta^{13}C$. Taken together, the data suggest that the primary mechanism for the reduction of photosynthesis by epidermal leaf mining by *P. populiella* is the failure of stomata to open normally on bottom-mined leaves.

◆ **Wagner, D. and P. Doak. 2013.** Long-term impact of a leaf miner outbreak on the performance of quaking aspen. Can. J. For. Res. 43(6): 563-569, 10.1139/cjfr-2012-0486

Author abstract. The aspen leaf miner, *Phyllocnistis populiella* Cham., has caused widespread and severe damage to aspen in the boreal forests of western North America for over a decade. We suppressed *P. populiella* on individual small aspen ramets using insecticide at two sites near Fairbanks, Alaska, annually for 7 years and compared plant performance with controls. Insecticide treatment successfully reduced leaf damage by *P. populiella* during most years and had little effect on herbivory by externally feeding invertebrates. By the end of the study, control ramets had suffered a reduction in height and girth relative to treated ramets and to the original, pretreatment size. Control ramets produced smaller leaves during some years and, after 7 years, produced fewer total shoots and leaves than ramets sprayed with insecticide. Treatment did not affect mortality, but at the warmer of the two sites, ramets sustaining ambient levels of leaf mining were significantly more likely to die back to basal sprouts than those treated with insecticide. We conclude that a decade of *P. populiella* outbreak has caused strongly negative effects on aspen development and the production of aboveground tissues.

◆ **Werner, R.A. 2002.** Effect of ecosystem disturbance on diversity of bark and wood-boring beetles (Coleoptera: Scolytidae, Buprestidae, Cerambycidae) in white spruce (Picea glauca (Moench) Voss) ecosystems of Alaska [microform] . Res. Pap. PNW-RP-546. Portland, OR: U.S.
Department of Agriculture, Forest Service, Pacific Northwest Research Station. 15 pp.

Author abstract. Fire and timber harvest are the two major disturbances that alter forest ecosystems in interior Alaska. Both types of disturbance provide habitats that attract wood borers and bark beetles the first year after the disturbance, but populations then decrease to levels below those in undisturbed sites. Populations of scolytids, buprestids, and cerambycids are compared 1, 5, and 10 years after burning and timber harvest on flood-plain and upland white spruce sites. This paper reports the effects of ecosystem disturbance, such as silvicultural practices and prescribed fire, on the diversity of wood-inhabiting bark beetles and wood borers in upland and flood-plain white spruce stands in interior Alaska.

◆**Werner, R. A. 1964**. White Spruce Seed Loss Caused by Insects in Interior Alaska
Canad. Ent. 96: 1462-1464

Author Abstract: Insects caused serious damage to cones and seeds of white spruce during one of the five years of this study. A new seed and cone insect, *Pegohylemyia* sp., was recorded for the first time from Alaska. This insect destroyed an average of 50% of the seeds per cone.

◆ **Werner, R.A., E.H. Holsten, S.M. Matsuoka, and R.E. Burnside. 2006.** Spruce beetles and forest ecosystems in south-central Alaska: a review of 30 years of research. Forest Ecology and Management 227(3):195-206.

Author abstract. From 1920 to 1989, approximately 847,000 ha of Alaska spruce (*Picea* spp.) forests were infested by spruce beetles (*Dendroctonus rufipennis*). From 1990 to 2000, an extensive outbreak of spruce beetles caused mortality of spruce across 1.19 million ha of forests in Alaska; approximately 40% more forest area than was infested the previous 70 years. This review presents some of the most important findings from a diversity of research and management projects from 1970 to 2004 to understand the biology, ecology, and control of this important forest insect, and the causes and effects of their outbreaks. It is suggested that future research should examine the long-term effects of the spruce beetle outbreaks and climate variability on forest ecosystems in the region. Research into how different management actions facilitate or interrupt natural successional processes would be particularly useful.

◆**Werner, R.A., K.F. Raffa, and B.L. Illman. 2006**. Chapter 9. Dynamic of phytophagous insects and their pathogens in Alaskan boreal forests. In: S. Chapin (ed.). Alaska's changing boreal forests. Oxford University Press, Oxford. Pp. 133 – 146.

Author abstract: Boreal forests support an array of insects, including phytophagous (plant-eating) insects, saprophagous (detritus-eating) insects, and their associated parasites, predators, and symbionts. The phytophagous species include folivorous leaf chewers and miners, phloeophagous cambial and sapwood borers, stem gallers, and root feeders. Biological diversity and distribution of insect species exhibit predictable patterns among vegetation types (Werner 1994a). In this chapter, we discuss how phytophagus species of insects differ among plant communities and how various populations of insects react to disturbances that alter forest stand composition and density.

◆ **Wurtz, T.L., J. Alden, J. Graham, and M. Kromrey. 1999.** A trial of Lutz spruce (Picea xlutzii Little) resistance to the spruce beetle (Dendroctonus rufipennis Kirby). p. 85 in: Proc. of the Alaska Reforestation Council April 29, 1999 Workshop. Anchorage, AK. Univ. of Alaska Fairbanks Agric. & For. Exp. Sta. Misc. Publ. 99-8. 85 pp.

Author abstract. In September 1998 we began a study of spruce beetle resistance among Lutz spruce trees from four populations on the West Side of Kenai Peninsula. The catalyst for this effort was an exceptional seed crop in 1998. Relative to their immediate neighbors of equal size and age, 28 seed trees were selected for 1) fewer successful attacks, more vigor, and profuse resin flow from beetle entrance or exit holes; and 2) smooth bark, prominent Sitka spruce traits (morphology), and green foliage.

Severity of the spruce beetle outbreak in the hybrid zone decreased with increasing latitude and tree species diversity. Infestation s ranges from 10% of trees larger than five inches (13 cm) in stem diameter at 4.5 fee (137 cm) in the East Homer population, (59° 46' N. Lat., 151° W. Long.) to 55% in the Summit Lake population (60° 43' N. Lat., 149° W. Long.).

Susceptibility of Lutz spruce to the spruce beetle will be tested in two groups: trees grown from seed of 28 trees collected in the 1980s before the populations were heavily infested, and seed of trees collected from the same sites in 1998. The spruce beetle killed most of the former trees during this period. These of the 1980 collections will be the "control" or "not resistant" group in the study. Since seeds collect in 1998 were usually from the only surviving trees, the second group is expected to demonstrate more resistance to the spruce beetle that the control group. Seedlings are being grown in a Canadian nursery for outplanting at five sites on Kenai Peninsula in June 2000.

◆**Yemshanov, D.; Koch, F.H.; Ben-Haim, Y; Smith, W,D. 2010a**. Robustness of risk maps and survey networks to knowledge gaps about a new invasive pest. Risk Analysis. 30(2): 261-276.

Author abstract: In pest risk assessment it is frequently necessary to make management decisions regarding emerging threats under severe uncertainty. Although risk maps provide useful decision support for invasive alien species, they rarely address knowledge gaps associated with the underlying risk model or how they may change the risk estimates. Failure to recognize uncertainty leads to risk-ignorant decisions and miscalculation of expected impacts as well as the costs required to minimize these impacts. Here we use the information gap concept to evaluate the robustness of risk maps to uncertainties in key assumptions about an invading organism. We generate risk maps with a spatial model of invasion that simulates potential entries of an invasive pest via international marine shipments, their spread through a landscape, and establishment on a susceptible host. In particular, we focus on the question of how much uncertainty in risk model assumptions can be tolerated before the risk map loses its value. We outline this approach with an example of a forest pest recently detected in North America, *Sirex noctilio* Fabricius. The results provide a spatial representation of the robustness of predictions of *S. noctilio* invasion risk to uncertainty and show major geographic hotspots where the consideration of uncertainty in model parameters may change management decisions about a new invasive pest. We then illustrate how the dependency between the extent of uncertainties and the degree of robustness of a risk map can be used to select a surveillance network design that is most robust to knowledge gaps about the pest.

◆**Yemshanov, D.; Koch, F.H.; Ben-Haim, Y.; Smith, W.D. 2010b**. Detection capacity, information gaps and the design of surveillance programs for invasive forest pests. Journal of Environmental Management. 91: 2535-2546.

Author abstract: Integrated pest risk maps and their underlying assessments provide broad guidance for establishing surveillance programs for invasive species, but they rarely account for knowledge gaps regarding the pest of interest or how these can be reduced. In this study we demonstrate how the somewhat competing notions of robustness to uncertainty and potential knowledge gains could be used in prioritizing large-scale surveillance activities. We illustrate this approach with the example of an invasive pest recently detected in North America, *Sirex noctilio* Fabricius. First, we formulate existing knowledge about the pest into a stochastic model and use the model to estimate the expected utility of surveillance efforts across the landscape.

The expected utility accounts for the distribution, abundance and susceptibility of the host resource as well as the value of timely *S. noctilio* detections. Next, we make use of the info-gap decision theory framework to explore two alternative pest surveillance strategies. The first strategy aims for timely, certain detections and attempts to maximize the robustness to uncertainty about *S. noctilio* behavior; the second strategy aims to maximize the potential knowledge gain about the pest via unanticipated (i.e., opportune) detections. The results include a set of spatial outputs for each strategy that can be used independently to prioritize surveillance efforts. However, we demonstrate an alternative approach in which these outputs are combined via the Pareto ranking technique into a single priority map that outlines the survey regions with the best trade-offs between both surveillance strategies.

◆ **Yukon Energy, Mines and Resources. 2014.** Tomentosus Root Disease, Yukon Forest Health – Forest Insect & Disease Pamphlet #22. Forest Management Branch, accessed 22FEB2014 at http://www.emr.gov.yk.ca/forestry/pdf/forest_health22.pdf.

Author abstract. Tomentosus root disease (*Inonotus tomentosus*) is a slow growing root rot of coniferous trees, particularly spruce (Picea spp.). Tomentosus is assumed to occur throughout the host range in Yukon, however only limited surveying has occurred. Tomentosus does cause tree mortality but generally takes decades to kill mature trees. Surveys in the Shakwak Trench and LaBiche River found that more than 40% of trees were infected by the disease, but signs were limited almost entirely to the incipient stain, with only 1% of the trees showing advanced root decay. Disease incidence was higher on wetter sites (i.e. Dezadehash Lake and Labiche River). In managed forests, tomentosus can cause more severe mortality where infected stumps provide inoculum for young regenerating trees.

Section 8
NON-NATIVE AND INVASIVE SPECIES

SUMMARY

Tricia L. Wurtz, U.S.D.A. Forest Service, State and Private Forestry
Nicholas J. Lisuzzo, U.S.D.A. Forest Service, State and Private Forestry

Plants that are not native to south-central and interior Alaska can play two roles in reforestation. First, non-native tree species can be intentionally planted in a harvested area as crop species, an approach which has both potential benefits and potential drawbacks. Second, non-native plants (both woody and herbaceous) can be unintentionally introduced, or invade, harvested areas. Such invaders may compete with the regeneration of crop trees and inhibit reforestation.

In Alaska, numerous plantings and reforestation trials using non-native tree species have been established, in a variety of locations across the state (Alden 2005; Alden 2006). Lodgepole pine (*Pinus contorta*) is the non-native species most commonly tested; it has also been widely planted as a non-native in Iceland, New Zealand and Sweden (Cushing 2005; Elfving et al., 2001; Engelmark et al., 2001; Ledgard 2001). Other species planted on a trial basis in Alaska include Scotch pine (*Pinus sylvestris)*, Jack pine (*Pinus banksiana*), Siberian larch (*Larix sibirica*), Dahurian larch (*Larix gmelinii*), Siberian fir (*Abies sibirica*), Balsam fir (*Abies balsamea*), Norway spruce (*Picea abies*) and Blue spruce (*Picea pungens*). The success of these plantings varies from stands of well-established trees now producing viable seed to 100 percent mortality; information on the plantings varies in completeness as well (Alden 1988).

There are several potential benefits of using non-native tree species in reforestation. The species diversity of Alaska's native forests is comparatively very low, with only four native tree genera occurring north of 60 degrees latitude (Alden 2014). This lack of diversity makes the forest vulnerable to insect and pathogen outbreaks, and may reduce its ability to adapt to climate change. Non-natives can improve silvicultural productivity (Elfving et al., 2001), but can also require changes in silvicultural management practices (Andersson et al., 1999). Other potential drawbacks include introducing species which unexpectedly behave invasively once planted (Despain 2001; Ledgard 2001; Sykes 2001), reducing the biodiversity of the native ecosystem (Engelmark et al., 2001; Ledgard 2001), species fragmentation (Knight et al., 2001) and unintentionally introducing non-native pathogens or insects associated with the new tree species (Conn et al., 2008; but see Lindelow and Bjorkman 2001). Such invaders could theoretically build their populations on non-native plantings, then shift to native species (Ennos 2001). After being intentionally planted in New Zealand beginning in the 1880s, lodgepole pine is now considered a weedy species there and is seldom planted (Ledgard 2001). Karlman (2001) describes severe *Scleroderris* canker damage that occurred on lodgepole pine in northern Sweden in the 1990s. Though not a silvicultural species, the ornamental tree species European birdcherry (*Prunus padus*) provides an Alaskan example of the unintended effects that can accompany widespread plantings of non-native species. This small tree has been widely planted in Anchorage yards and gardens since around 1960. Spread by seed-eating birds, it has aggressively invaded Anchorage's urban parklands and is replacing native tree and shrub species in riparian corridors (Roon 2011, Roon et al., 2015)

Peterken (2001) describes the positive and negative effects of non-native tree introductions over the last 400 years in Britain, pointing out that the ecological consequences have not yet been fully manifested. Similarly, vertebrate animals in Sweden may still be adjusting to the presence of lodgepole pine there (Sjoberg and Danell 2001). An Alaska DNR, Division of Forestry fact sheet (2004) reviews the uncertainties associated with planting non-native tree species in Alaska.

Non-native plants can also play a role in reforestation when they either invade or are unintentionally introduced into harvested areas. Such plants can be introduced and spread when seeds or other propagules are carried on footwear (Ware et al., 2012), stuck to vehicles (Pickering and Mount 2010; Taylor et al., 2012), in the soil of containerized plants (Conn et al., 2008), in hay and straw (Conn et al., 2010) and a variety of other ways.

To date, more than 200 plant species not native to Alaska have become naturalized in the state (AKEPIC 2015; Carlson and Shephard 2007). Alaska has a system for ranking the invasiveness of non-native plants (Carlson et al., 2008); ranks range from zero (not at all invasive) to 100 (highly invasive). Typically, invasive plants first become established in a human-disturbed system (for example, a roadside or a construction site) and then spread along corridors of human disturbance (roadsides, trails). Burned areas, especially those on the road system, represent large disturbed areas that are vulnerable to colonization by invasive plants (Villano 2008; Spellman et al., 2014).

The invasive plant species seemingly most likely to affect reforestation are those that would compete with crop tree seedlings and saplings, but at present, no invasive plants in Alaska are known to have spread into harvested areas in Regions II and III. A 2014 survey of seven harvested areas in the Tanana Valley State Forest found no non-native species in the harvested areas themselves, but observed seven non-native plant species occurring in the staging and log deck areas (Wurtz and Lisuzzo, pers. comm. 2014). Based on their biology and their low invasiveness ranking scores, these species seem unlikely to affect reforestation either now or in the future. A different species, bird vetch (*Vicia cracca*), is perhaps the invasive plant in Alaska most likely to assume this role at some point in the future. Bird vetch is spreading rapidly along roadsides in both interior and southcentral Alaska, and several discrete clumps of bird vetch were observed growing on roadsides in the Tanana Valley State Forest in 2014 (Wurtz and Lisuzzo, pers. Comm., 2014). Graziano et al. (2012) suggest prompt action on small infestations of bird vetch, and provide advice on control methods for this species.

Information on non-native insects and diseases are discussed in the section of this bibliography devoted to forest insects and diseases. Very few invasive animals other than insects have established in Alaska's forests to date (Schrader and Hennon 2005). Of those, the ones that seem most likely to affect reforestation at some point in the future would be slugs and earthworms. Exotic earthworms have well-documented negative effects on forest ecosystems such as decreasing organic matter in the soil and reducing plant species richness (Saltmarsh 2012). In any case, at present the ecological effects of invasive species of any taxa in the boreal forest of North America remain poorly understood (Sanderson et al., 2012).

REFERENCES

◆ **AKEPIC. 2015.** Alaska Exotic Plant Information Clearinghouse database (http://aknhp.uaa.alaska.edu/maps/akepic/). Alaska Natural Heritage Program, University of Alaska, Anchorage. Accessed (January 30, 2015).

Compiler abstract: This interactive database provides information on the location of known populations of non-native species and data on survey history.

◆ **Alaska Dept. of Natural Resources Division of Forestry. 2004**. Frequently asked questions about reforestation with non-native trees in southcentral Alaska. Unpubl. Fact sheet. 3 pp.

Compiler abstract: This fact sheet addresses frequently asked questions about survival, susceptibility to disease, wildfire risk, wood value, and wildlife habitat impacts of lodgepole pine and Siberian larch planting in Alaska.

◆ **Alden, J. 2014.** Use of Non-native trees on mainland Alaska. Unpubl. notes for presentation to Reforestation Science & Technical Committee, Nov. 25, 2014. 4 pp.

Compiler abstract: This presentation addressed reasons for introducing non-native tree species to mainland Alaska and reviewed the best-adapted and productive non-native tree species for this region. The author also reviewed the history of field trials with non-native species in northern Alaska.

◆ **Alden, J. 2006.** Field survey of growth and colonization of non-native trees on mainland Alaska. US Forest Service, Pacific Northwest Res. Sta. PNW-GTR-664.

Author abstract. Six of nine nonnative boreal conifers in three genera (*Abies*, *Larix*, and *Pinus*) regenerated in 11 to 31 years after they were introduced to mainland Alaska. Lodgepole pine (*Pinus contorta* var. *latifolia* Engel.) and the Siberian larches (*Larix sibirica* Ledeb. and *L. sukaczewii* N. Dyl.) were the most widely introduced species and will likely be the first nonnative conifers to naturalize. Siberian larch grew up to six times more stem volume than white spruce in the first 40 years on upland sites, but was susceptible to the larch sawfly and a blue stain pathogen carried by bark beetles. On productive sites, lodgepole pine appeared to grow more stem wood than white spruce for about 35 years after planting. Snowshoe hares and moose were the most serious pests of the nonnative conifers. Balsam fir (*Abies balsamea* (L.) Mill.) was the only species to regenerate in an established moss understory. Growth and age relationships were negative for all adequately sampled nonnative conifers and positive for native white spruce (*Picea glauca* (Moench) Voss). Data were insufficient to assess niche availability for commercial use of productive nonnative conifers in mixed stands in Alaska. Survey results indicate that introduction and naturalization of noninvasive tree species may improve the diversity, stability, and productivity of managed forest ecosystems.

◆ **Alden, J.N. 2005.** Long-term reforestation demonstrations and research on mainland and SW Alaska. Alaska Refor. Council unpubl. report. May 7, 2003, updated Aug. 24, 2005. 12 pp.

Compiler abstract. This report is an inventory of active and inactive reforestation field demonstrations and research projects established in Alaska since about 1960. Forest development and tree improvement research including species, provenance, and variation within provenance demonstrations and studies are emphasized. After 1980, family variation in populations and family-progeny tests were established to estimate heritabilities and genetic gains from selection of quantitative traits. Natural and artificial reforestation methods, site preparation technology, size and age of container stocks, best planting dates, etc. are included in the list. Studies concerning regeneration harvest methods, stand improvement, vegetation control, plantation release, stocking, are excluded.

◆ **Alden, J.N. 1988.** Implications of research on lodgepole pine introduction in interior Alaska. U.S. Dept. of Agriculture, Forest Service, Pacific Northwest Research Station Res. Pap. PNW-RP 402. Portland, OR. 24 pp.

Author abstract. Growth, winter injury, and mortality were evaluated for 12-year-old trees of 11 subarctic lodgepole pine provenances and a jack pine provenance at Fairbanks, Alaska. Provenances from northeast British Columbia grew more than 0.003 cubic meter of wood per tree annually from 9 to 12 years after outplanting. The species sustained snow damage and winter injury, however, and could be at high risk in long-term management on severe sites in Alaska. Provenance x site interactions were not significant for mortality, tree height, and volume after the same stock grew for 10 seasons at Fairbanks and Whitehorse, Yukon.
Height and environmental injury of 3-year-old seedlings from 18 subarctic lodgepole pine and a jack pine x lodgepole pine swarm from Fort Nelson River, British Columbia, were evaluated at two sites in the interior and one site in south-central Alaska. Seedlings from high-altitude provenances grew more slowly and sustained less environmental injury after outplanting than seedlings from low-altitude provenances. More seedlings of the jack pine x lodgepole pine provenance sustained injury, but they grew taller than seedlings of the lodgepole pine provenances in the nursery and after two growing seasons in the field. Additional research is necessary to identify and determine growth and yield of superior jack, lodgepole, and jack pine x lodgepole pine provenances for a wide range of sites in Alaska.

◆ **Andersson, B., Engelmark, O., Rosvall, O., Sjoberg, K., 1999.** Environmental impact analysis concerning lodgepole pine forestry in Sweden. SkogForsk Report No. 3, 93 pp.

Author abstract. This report presents an analysis of the ecological consequences of forestry with Canadian lodgepole pine introduced into Sweden. The report includes a compilation of present knowledge in the area, research priorities, and proposed measures for dealing with the negative environmental consequences that could arise. The point of departure of the analysis is a description of the properties of lodgepole pine, including species-specific characteristics of the tree, and changes in stand environment and silvicultural management practices that can be expected. The report describes the dispersal capacity of lodgepole pine in its new Swedish environment and the effects of host-parasite interactions. Thereafter, ecological effects on the capacity of the soil for sustainable production and on biological diversity at various scales (tree, stand, landscape) are analysed. Lodgepole pine forestry is also considered in relation to current laws and regulations as well as national and international environmental goals. At the end of the report, a strategy is proposed for handling the inevitable uncertainties associated with the introduction of exotic species.

◆ **Bowser, M.L. 2010.** Exotic Earthworms in Alaska: an Insidious Threat. Unpubl. poster for Alaska Invasive Species Conference, October 26-28, 2010, Fairbanks, AK. US Fish & Wildlife Service, Kenai National Wildlife Refuge, Soldotna, AK.

Author text. As with much of northern North America, most of Alaska is naturally devoid of earthworms due to extensive glaciations over the last 100,000 years. All of the earthworms commonly encountered in Alaska are recent introductions from Europe. A checklist of the 16 earthworm species known from Alaska (1 native, 13 established exotics, and 2 exotics collected from artificial situations) and distribution records are provided.

Introduced earthworms have the potential to dramatically alter natural systems by rapidly consuming the upper organic soil layers. In the Upper Midwest, European earthworms have removed litter and duff from the forest floor at rates of up to 10 cm/yr, causing direct harm to native biota dependent on a thick organic layer. Declines of native plants, ovenbirds, red-backed voles, shrews, and salamanders have been attributed to the activities of earthworms. A more insidious threat is the prospect of invasional meltdown, where exotic species interact positively. In this case, earthworms alter soil properties in a way that is likely to favor exotic plants. Little can be done to control earthworms once they have become established. However, earthworms have limited dispersal ability; almost all long-range dispersal of earthworms is human-caused.

Recommendations
• The public should be educated about earthworms as potentially harmful exotic species.
• Infested soil, compost, worm castings, and plantings should not be sold or transported.
• Fishing regulations should explicitly and clearly disallow the use of live earthworms as bait.
• Tires of forestry equipment, trucks, and ATV’s should be cleaned to prevent the spread of eggs and cocoons trapped in soil between tire treads.

◆ **Carlson, M.L., I.V. Lapina, M. Shephard, J.S. Conn, R. Densmore, P. Spencer, J. Heys, J. Riley, and J. Nielsen. 2008.** Invasiveness ranking system for non-native plants of Alaska. USDA Forest Service, Alaska Region. Publication R10-TP-143. Forest Service. Alaska Region.

Author abstract. Alaska is beginning to experience increased non-native plant establishment, spread, and devaluation of its lands. In response to this increasing threat, we developed a ranking system to evaluate the potential invasiveness and impacts of non-native plants to natural areas in Alaska. This ranking system is designed to be a robust, transparent, and repeatable procedure to aid land managers and the broader public in identifying problematic non-native plants and for prioritizing control efforts. Numerous ranking systems exist, but none are suited to predicting negative impacts to natural systems in Alaska. We created a ranking system that incorporated components from other systems, in which species are ranked by a series of questions in four broad categories: ecosystem impacts, biological attributes, distribution, and control measures. In addition, we include a climate screening procedure to evaluate the potential for establishment in three ecogeographic regions of Alaska. As additional information becomes available, the ranks may change over time. Here we present background and justification for this system and include the ranks of 113 non-native species that are in the state or are likely to be introduced in the future.

◆ **Carlson, M.L. and M. Shephard. 2007**. Is the spread of non-native plants in Alaska accelerating? pp. 111-127 in: Meeting the challenge: Invasive plants in Pacific Northwest ecosystems. US Forest Service Pacific Northwest Res. Sta. PNW-GTR-694. 166 pp.

Author abstract. Alaska has remained relatively unaffected by non-native plants; however, recently the state has started to experience an influx of invasive non-native plants that the rest of the U.S. underwent 60–100 years ago. With the increase in population, gardening, development, and commerce there have been more frequent introductions to Alaska. Many of these species, such as meadow hawkweed (*Hieracium caespitosum*), Canada thistle (*Cirsium arvense*), and spotted knapweed (*Centaurea biebersteinii*), have only localized populations in Alaska. Other species such as reed canary grass (*Phalaris arundinacea*) and white sweetclover (*Melilotus officinalis*), both formerly used in roadside seed mixes, are now very widespread and are moving into riparian areas and wetlands. We review the available literature and Alaska's statewide invasive plant database (AKEPIC, Alaska Exotic Plant Clearinghouse) to summarize changes in Alaska's non-native flora over the last 65 years. We suggest that Alaska is not immune to invasion, but rather that the exponential increase in non-native plants experienced elsewhere is delayed by a half century. This review highlights the need for more intensive detection and rapid response work if Alaska is going to remain free of many of the invasive species problems that plague the contiguous U.S.

◆ **Conn, J.S., C.A. Stockdale, and J.C. Morgan. 2008.** Characterizing Pathways of Invasive Plant Spread to Alaska: I. Propagules from Container-Grown Ornamentals. Invasive Plant Science and Management 2008 1:331–336.

Author abstract. To determine the extent and nature of container-grown plant soil as a pathway for introduction of exotic plant species to Alaska, soil from container-grown ornamentals was obtained from vendors and was incubated in the greenhouse. Fifty-four plant species were identified growing in containers or germinating from the soil, and included Canada thistle—a prohibited weed in Alaska—and nine other species listed as invasive in Alaska. The number of species and estimated seed bank were very low for soil from vegetable starts/herbs and herbaceous bedding plants (<2 seedlings/L soil), but was greater for soil from containers containing woody plants, especially balled and burlapped ornamentals (20 seedlings/L soil). Container alien plant seed bank size was strongly related to type of soil. Potting (soil-less) soil contained 1.2 germinating seeds/L, soil-based soil 5.5 seeds/L, and mineral soil 18.7 seeds/L. Growers and vendors were variables that also influenced the size of the container seed bank, suggesting that weed management practiced during production and at the point of sale can greatly influence seed banks of ornamental containers.

◆ **Conn, J.S., C.A. Stockdale, N.R. Werdin-Pfisterer, and J.C. Morgan. 2010.** Characterizing Pathways of Invasive Plant Spread to Alaska: II. Propagules from Imported Hay and Straw. Invasive Plant Science and Management. 3:276-285.

Author abstract. The extent and nature of spread of exotic plant species to and within Alaska by shipment of hay and straw was studied. The amounts of hay and straw imported into Alaska and the amounts and types of seed in imported and locally produced hay and straw was determined. We purchased alfalfa hay, wheat straw, ryegrass straw, and timothy hay produced in Washington and Oregon (WA–OR) and locally produced straw and hay. The hay and straw were shaken over screens, and the remaining fines were mixed with sterile potting soil and incubated in the greenhouse. Forty-nine plant species were identified from hay and straw, nine of which are ranked as invasive in Alaska, including downy brome, foxtail barley, hare barley, narrowleaf hawksbeard, and quackgrass—a prohibited weed in Alaska. The number of seeds ranged from 0 to 6,205 seeds kg^{-1}, with an average of 585 seeds kg^{-1}, and the number of species ranged from 0 to 12, with an average of 4.2 species per bale. Crop seed comprised a large proportion of the germinated seeds in ryegrass straw, wheat straw, and timothy/brome hay (98, 78, and 62%, respectively), but was less prevalent (ranging from 0 to 38%) in the other three hay and straw crop types. Hay and straw from Alaska contained more total seeds and species than hay and straw from WA-OR, but the difference was not significant when only weed seed was used in the analysis. Alaska-grown timothy/brome hay contained significantly more total seed than alfalfa hay and wheat straw from WA–OR and Alaska-grown barley straw. The grower or distributor of the hay and straw also influenced the number of seeds and species among some crop types. Results of this study document that large numbers of alien plant species are transported by movements of hay and straw into and within Alaska.

◆ **Cushing, A. 2005.** The potential of lodgepole pine in Alaska . Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 90 pp.

Author abstract. The introduction of non-native trees should be informed by various perspectives. In the case of forestry in high-latitude regions, managers face the challenge of finding cold-hardy species adequately adapted to harsh climatic environments; Lodgepole pine (Pinus contorta Dougl. Ex. Loud.) has been introduced to three regions at or above its natural northern latitudinal extent; Alaska, Iceland, and northern Sweden. Analysis of interviews in each region revealed the structure of common arguments, including underlying assumptions and perceptions of the natural world. Results of a mail-out-survey to the Alaskan public indicate that a considerable portion of the public is concerned about the possibility for adverse ecological effects on the native ecosystem. However, acceptance of non-native trees increased under certain circumstances; e.g. small-scale ornamental plantings, and when economic benefit is demonstrated. In comparisons of twenty-year growth data of lodgepole pine in Alaska with native white spruce (Picea glauca), lodgepole pine achieved greater height, diameter, and volume. The response of lodgepole pine in all three regions to scenarios of climate change was predicted using tree-ring analysis. Results indicate a negative response (reduced growth) in the Fairbanks area, a positive response (increased growth) in Delta and Glennallen, and a positive response at all but one Icelandic site and both Swedish sites. Overall, lodgepole pine appears relatively well-adapted to the present and modeled future environments of interior Alaska, Iceland, and northern Sweden.

◆ **Despain, D.G. 2001.** Dispersal ecology of lodgepole pine (*Pinus contorta* Dougl.) in its native environment as related to Swedish forestry. For. Ecol. and Management 141(1-2): 59-68.

Author abstract. Lodgepole pine (*Pinus contorta* Dougl.) covers extensive areas of the mountains of western North America. It has evolved into four subspecies, each adapted to slightly different environmental conditions. All are adapted to reproduce following fire. Subspecies *latifolia* is the most extensive and economically important in North America. Serotiny is common in this subspecies, but trees bearing nonserotinous cones can be found in most stands, sometimes constituting more that 70% of the trees. Cone crops are produced yearly and seed loss to seed predators, insects and diseases are minimal. Germination and establishment occurs across a broad range of conditions allowing lodgepole pine to grow on poor sites as well as highly productive sites. These characteristics give lodgepole pine the ability to be highly invasive in new areas of suitable habitat.

◆ **Elfving, B., T. Ericsson, and O. Rosvall. 2001.** The introduction of lodgepole pine for wood production in Sweden—a review. Forest Ecology and Management Volume 14(1-2): 15-29.

Author abstract. The species-specific properties and the environmental requirements of lodgepole pine (LP) in both its native environment and as an exotic are reviewed in order to describe the large-scale introduction of this tree to Sweden, where the planted area has reached about 600,000 ha during a 25-year period. LP is estimated to produce 36% more wood than Scots pine (SP) and survives better in the young stages, but is less stable against wind and snow load after being planted. Other species differences are discussed in terms of resource acquisition, biomass allocation and losses, as well as the resistance to abiotic and biotic stresses. The experiences of silvicultural practices are described, along with initial progress in tree breeding and seed orchard programmes. The influence of tree and stand characteristics, e.g. rotation age, stand density, species composition and stand distribution in the landscape, are discussed in order to analyze the ecological and environmental consequences of current and future management alternatives.

◆ **Engelmark, O., K. Sjöberg, B. Andersson, O. Rosvall, G.I. Ågren, W.L. Baker, P. Barklund, C. Björkman, D.G. Despain, B. Elfving, R.A. Ennos, M. Karlman, M.F. Knecht, D.H. Knight, N.J. Ledgard, Å. Lindelöw, C. Nilsson, G.F. Peterken, S. Sörlin, M.T. Sykes. 2001**. Ecological effects and management aspects of an exotic tree species: the case of lodgepole pine in Sweden. Forest Ecology and Management. Volume 141(1-2): 3-13.

Author abstract. The North American tree *Pinus contorta* var. *latifolia* was experimentally introduced in Sweden already in the 1920s, and has been used in Swedish forestry on a large scale since the 1970s. These plantations now cover 565,000 ha, mainly in the northern area. In this paper we summarize and discuss existing ecological knowledge of this species introduction. With regard to long-term sustainability we suggest management means to minimize harmful effects of the introduction on ecosystems. These include aspects of self-dispersal, pests, ecosystem and landscape structures, and also ecological processes and biodiversity. We also focus on observed and possible interactions in the ecosystems. As *Pinus contorta* seeds are disseminated and trees regenerated outside initial plantations, this may have future bearings on biodiversity. We suggest a strategy which takes account of the uncertainty in predicting future ecological effects. The strategy includes areal restrictions and zones without *Pinus contorta*, but also to set up a monitoring program. Observations of adverse effects from the plantations would then give the possibility to adjust *P. contorta* management.

◆ **Ennos, R.A. 2001. The introduction of lodgepole pine as a major forest crop in Sweden: implications for host–pathogen evolution.** Forest Ecology and Management 141(1-2): 85-96.

Author abstract. Theoretical and experimental investigations of natural selection in host–pathogen systems are reviewed and the general principles emerging from these studies are used to analyse the possible pathogenic consequences of introducing lodgepole pine into Sweden. Introduction of lodgepole pine *alone* is likely to pose a relatively low disease risk for native forests. The possible evolution of more aggressive populations of native Scots pine pathogens on highly stressed lodgepole pine plantations is, nevertheless, of some concern. These pathogens could, subsequently, transfer back on to Scots pine and cause an increase in damage levels within native forests. The risk of this form of destabilising pathogen evolution occurring is, however, similar to the risk of evolving more aggressive pathogens on stands of native Scots pine growing under stressed conditions.

In contrast to the conclusions drawn above, the introduction of lodgepole pine pathogens from North America into Sweden has the potential to cause very severe damage not only to native Scots pine, but also to lodgepole pine growing as an exotic. The most important measures needed to guard against pathogenic problems are those that minimise the risk of introduction of lodgepole pine pathogens into Sweden. One practical step that can be taken is to curtail importation of lodgepole pine seed and encourage the development of well adapted Swedish ‘land races’ of lodgepole pine from germplasm already present in the country.

◆ **Graziano, G., A. Grant, and T. Wurtz. 2012.** Control of bird vetch *(Vicia Cracca*). Univ. of Alaska Coop. Extension Service. Invasive Plant Issues PMC-00341.Fairbanks, AK. 2 pp.

Compiler abstract. Bird vetch (*Vicia cracca*) spreads rapidly; it reproduces by seed and vegetatively through spreading rhizomes. Once established, bird vetch is able to flourish in a range of conditions and it is tolerant of fire and drought. Unlike many invasives, bird vetch is also capable of invading undisturbed areas. Bird vetch is a frustration to home gardeners and is a concern in natural areas, small grain fields, vegetable gardens and small fruit orchards. This publication covers impacts, identification, and control options for bird vetch, including an integrated pest management treatment plan.

◆ **Karlman, M. 2001.** Risks associated with the introduction of *Pinus contorta* in northern Sweden with respect to pathogens. Forest Ecology and Management 141(1-2): 97-195.

Author abstract. Severe damage by *Scleroderris* canker, caused by the fungus *Gremmeniella abietina*, was recorded in provenance and progeny tests as well as in conventional plantings of *Pinus contorta* in areas with a harsh climate in northern Sweden in 1987. Damage was related to a period with extreme weather conditions. The Swedish Forestry Act placed restrictions on the planting programme of *P. contorta* in 1987, 1989 and 1991. The disease situation in northern

Sweden in the mid 1990s is discussed as well as the risks associated with the introduction of exotics in relation to the historical background. Attention is also drawn to parasitic fungi, which are infecting *P. contorta* in its natural range in western Canada, and to the potential threat they represent to the indigenous *Pinus sylvestris* in Sweden.

◆ **Knight, D.A., W.L. Baker, O. Engelmark, and C. Nilsson. 2001.** A landscape perspective on the establishment of exotic tree plantations: lodgepole pine (*Pinus contorta*) in Sweden. Forest Ecology and Management 141(1-2): 131-142.

Author abstract. This paper reviews some of the potential effects of plantations of the North American lodgepole pine (*Pinus contorta*) on landscapes in Sweden dominated by Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), and, after major disturbances, by several deciduous trees (*Betula pendula*, *B. pubescens* and, less commonly, *Populus tremula*). Also, we determine the proportions of a specific landscape in Sweden that are at varying distances from lodgepole pine and the degree to which landscape fragmentation may be increased by lodgepole pine plantations. The results indicate that all portions of the study area could receive wind-dispersed seed from existing lodgepole pine plantations, but that the level of additional fragmentation introduced by lodgepole pine in an already highly fragmented landscape is low. In general, however, the effects of forest fragmentation are compounded when the regeneration of native species is replaced by plantations of introduced species because new patch types are introduced. Even if the exotic species develop a forest structure similar to that produced by native species, a different kind of fragmentation — species fragmentation — is created that persists much longer than if only native species are involved. The ecological effects of introducing lodgepole pine, with a tree structure very similar to that of the native Scots pine, cannot yet be predicted with confidence, but managers should be cautious about creating new plantations in landscapes where there is a desire to avoid the invasion of an exotic species. Some research priorities are identified.

◆ **Ledgard, N. 2001.** The spread of lodgepole pine (*Pinus contorta*, Dougl.) in New Zealand. Forest Ecology and Management 141(1-2): 43-57.

Author abstract. Lodgepole pine (*Pinus contorta*, Dougl.) was introduced to New Zealand in about 1880. It is the most vigorous naturally regenerating introduced conifer, which has led to large areas of unwanted spread or ‘wildings’. Wildings threaten existing indigenous flora and fauna, visual landscape and land use values. The area affected by all conifer natural regeneration is estimated at 150,000 ha of which approximately two thirds is lodgepole pine. Control operations have been undertaken in New Zealand since the 1960s. The high ‘weed’ potential of lodgepole pine, coupled with its low grower and market acceptance in New Zealand, means that the species is seldom planted nowadays.

Lodgepole pine spreads more vigorously than other introduced conifers as it cones earlier, is capable of producing seed and wildings at higher altitudes, and has lighter seed allowing dispersal over wide areas. Spread occurs most readily on ungrazed land with low vegetation density, and is least likely to occur in intact, dense vegetation, or where intensive grazing is practiced. Direction and distance of spread from parent trees is predictable. Most wildings occur initially as fringe spread within 50 m downwind of parent trees. Distant spread (measured in kilometers) is usually associated with trees on take-off sites exposed to the wind, such as hilltops and ridges. Spread commonly occurs in ‘waves’, about once every 5 years for fringe spread, and once every 10–20 years for distant spread.

Research on seed production, dissemination and the factors influencing seedling establishment has resulted in the development of strategies for the prevention and control of spread. The major aspects to consider for new plantings are siting, planting design and surrounding land management. Where large areas of spread exist, containment is often the most practical recommendation. Eradication is by burning, hand pulling (small seedlings only), felling and application of chemicals to stumps or foliage.

Lodgepole pine was the first conifer to attract significant adverse attention due to its propensity for natural regeneration, but concern about the spread of introduced conifers is now general, especially in the hill and high country grasslands of the eastern South Island. This concern has been promoted by new ‘effects-based’ resource management legislation which is currently being implemented by territorial authorities.

◆ **Lindelow, A., C. Bjorkman. 2001.** Insects on lodgepole pine in Sweden — current knowledge and potential risks. Forest Ecology and Management 141(1-2): 107-116.

Author abstract. Eighty species of forest insects have thus far been recorded feeding on lodgepole pine in the Nordic countries (61 in Sweden). The list includes species that have Scots pine as their main host and which feed on needles, flowers, cones, and shoots, as well as species boring in the phloem and xylem of dead or dying Norway spruce. Contrary to our expectations, most of the insect species that have colonised lodgepole pine in Sweden can be considered specialists (with regard to host plant range and feeding mode) rather than generalists. We suggest that the current dominance of specialised insect herbivores is related to the similarity in chemistry and morphology between lodgepole and Scots pine.

Only a few of the species considered to be pests have caused considerable damage in lodgepole pine stands in the Nordic countries. The most severe damage has been caused by the needle feeders *Neodiprion sertifer* and *Anthonomus phyllocola. Hylobius abietis*, the most harmful forest insect species in Scandinavia, attacks lodgepole pine seedlings to about the same degree as it attacks Scots pine and Norway spruce and causes similar levels of mortality. Other pest species reported to have caused considerable damage to lodgepole pine are *Pissodes validirostris* (cones) and *Rhyacionia bouliana* (shoots).

No insect species native to North America and living on lodgepole pine have yet to become established in the Nordic countries since the introduction of this exotic tree species. The risk of large-scale damage in Sweden is discussed in relation to the distribution and management of lodgepole pine.

◆ **Martinsson, 0. 1994.** Yield of *Larix sukaczewii* Dyl. in northern Sweden. Studia Forestalia Suecica 196. 20 pp. ISSN 0039-3150, ISBN 91-576-5007-1.

Author abstract. The stem volume yield of twenty small stands of larch, mainly Larix sukaczewii Dyl., was studied in northern Sweden. The stand age range was 34-89 years. On the most productive sites trees attain a dominant height of 27 m at age 60 years. Tree height increment is still continuing at age 90 years. The productivity of larch varies widely, depending on site quality. During a 100-year rotation, the total volume yield of larch on medium sites was calculated at 500 m3 ha-', and at 1000 m3 ha-' on the most productive sites (both including bark). On the most productive sites, stem volume yield of larch exceeded that of indigenous conifers by 10-25 per cent (excluding bark). On poor, dry, flat or waterlogged sites the yield of larch was inferior to that of indigenous conifers. On high-altitude sites, surprisingly high yields were observed.

◆ **Martinsson, O. and J. Lesinski. 2007.** Siberian larch. Forestry and Timber in a Scandinavian Perspective. JiLU Jämtlands County Council Institute of Rural Development. Tema Skog, 840 73 Bispgården, Sweden. 90 Pgs. (www.jilu.se)

Author preface and jacket note. This book is dealing with Siberian larch is different aspects of biology, ecology, forestry, and timber. It is aimed for foresters and forest land owners, as well as teachers and administrators of forests, and everybody interested in trees. The book has been produced within the SIBLARCH project, which was a cooperative, international, Northern Periphery project between forest and timber organizations in Sweden, Norway, Iceland, Finland, and Russia 2005-2007. The book summarizes the activities in the SIBLARCH project and some of the research performed before that project.

Larch is a northern and high altitude group of tree species. Although we have more than 250 years of experience of larch in Scandinavia it has not been widely used. There are two main reasons: Pulp industry has not been supporting research on larch since the larch wood properties are not very well aimed for paper production and, second, seed sources from the main area of larch, Russia, has not been available for research until the 1990s. However, larch "the oak of the north" has a great potential in the Scandinavian forestry and the larch timber has a wide field of application in all kinds of outdoor timber construction as well as indoor. Larch is also an appreciated landscape element and important enrichment to the Scandinavian forest ecosystems.

◆ **Peterken, G.F. 2001.** Ecological effects of introduced tree species in Britain. Forest Ecology and Management 141(1-2): 31-42.

Author abstract. Non-native trees have been introduced to Britain and native trees have been redistributed for over 2000 years, but most species were introduced in the last 400 years, and the ecological consequences have not yet been fully manifested. Introduction has been followed by various forms of adaptation to British conditions: (i) genetic changes in the trees themselves, (ii) assimilation into forest communities, (iii) colonisation by native plants, animals and fungi and (iv) gradual cultural acceptance. Nevertheless, some naturalised shrubs are widely regarded as ecologically damaging in semi-natural vegetation (e.g. *Rhododendron ponticum*, *Acer pseudoplatanus*), and the introduction of non-native conifers has allowed forestry to expand over moorland with substantial ecological effects.

◆ **Pickering, C. and A. Mount. 2010.** Do tourists disperse weed seed? A global review of unintentional human-mediated terrestrial seed dispersal on clothing, vehicles and horses. Journal of Sustainable Tourism. 18(2):239–256.

Author abstract. Human-mediated seed dispersal is recognised as an important, but under-researched, issue. To assess the potential for tourists to act as unintentional seed dispersal agents, we reviewed published and unpublished data on seed dispersal via clothing, vehicles (cars) and in/on horses and donkeys, all of which can be used by tourists. Seeds from 754 species of terrestrial plants have been collected from these vectors, 15% of which are internationally recognised environmental weeds. Seeds were collected from personal clothing and equipment (228 species), the fur of donkeys and horses (42 species), horse dung (216 species) and vehicles (505 species). Most were herbs (429 species) or graminoids (237 species) and native to Europe. Annual Poa, White Clover, Kentucky Bluegrass and Yorkshire Fog were the most frequent species. There have been eight studies specifically on tourists, which identified 12 species on clothing, 26 on vehicles and 133 from horse dung. Methods that minimise the risk of tourists as human-mediated dispersal agents may therefore be appropriate for some tourism activities/ : suggestions are made. Further sampling using standardised experimental techniques is required to assess the relative risk associated with specific tourist activities and locations and determine which, and how much, seed is transported.

◆ **Redko, G. and E. Mälkönen. 2005.** The Lintula Larch Forest. Review Article. Scandinavian Journal of Forest Research. 20: 252-282.

Author abstract. The Lintula Larch Forest, also called the Raivola Larch Forest, is one of the most magnificent cultivated forests in northern Europe. It has had a major impact on the cultivation of larch throughout the world, and it became part of the Unesco's World Heritage list in 1991. This article summarizes for the first time to an international audience the establishment, administration and management, stand development and research carried out in Lintula Park. It is based on Russian and Finnish papers and earlier unpublished results. The forest is located 63 km north-west of St Petersburg in the Karelian Isthmus. It was established by order of Peter the Great to supply the Russian fleet with timber for shipbuilding. Ferdinand Gabriel Fockel, a German forest expert, established the oldest stands in 1738 - 1750 with seed from the Province of Arkhangelsk. Since then the area of the forest has expanded and now the total area of larch stands is 55.9 ha; 23.5 ha of the old stands established in 1738 - 1851 still remain. The Lintula larch stands were famous for their high yield, but part of the reputation was based on small sample plots that were not representative of the stands. However, the high volumes of different tree stands are impressive. For example, in a 255-year-old stand with 339 trees ha -1 the volume of growing stock was 1284 m 3 ha -1. In small sample plots much higher volumes are found. The average annual growth of the oldest larch stands has never exceeded 6.2 - 7.2 m 3 ha -1 . The volume increment was, however, long-lasting, and annual growth started to decrease only after 148 - 166 years. Some plots had an increase in yield even at the age of 257 years. The yield of the larches clearly surpassed that of Norway spruce and Scots pine in nearby stands. The Lintula Larch Forest has provided valuable experience on the cultivation of larch. The root system of larch is relatively weak, and it is therefore susceptible to wind damage and rot fungi. An important conclusion drawn from the development of the Lintula Larch Forest is that the cultivation of larch is worthwhile only when grown as pure stands using intensive growing techniques.

◆ **Roon, D. A. 2011.** Ecological effects of invasive European bird cherry (*Prunus padus*) on salmonid food webs in Anchorage, Alaska streams. MSc. Thesis, University of Alaska Fairbanks. 111 pp.

Author abstract. Invasive species are a concern worldwide as they can displace native species, reduce biodiversity, and disrupt ecological processes. European bird cherry (Prunus padus) (EBC) is an invasive ornamental tree that is rapidly spreading and possibly displacing native trees along streams in parts of urban Alaska. The objectives of this study were to: 1) map the current distribution of EBC along two Anchorage streams, Campbell and Chester creeks, and 2) determine the effects of EBC on selected ecological processes linked to stream salmonid food webs. Data from the 2009 and 2010 field seasons showed: EBC was widely distributed along Campbell and Chester creeks; EBC leaf litter in streams broke down rapidly and supported similar shredder communities to native tree species; and EBC foliage supported significantly less terrestrial invertebrate biomass relative to native deciduous tree species, and contributed significantly less terrestrial invertebrate biomass to streams compared to mixed native vegetation, but riparian EBC did not appear to affect the amount of terrestrial invertebrate prey ingested by juvenile coho salmon (Oncorhynchus kisutch). Although ecological processes did not seem to be dramatically affected by EBC presence, lowered prey abundance as measured in this study may have long-term consequences for stream-rearing fishes as EBC continues to spread over time.

◆ **Roon, D., M. Wipfli, T.L. Wurtz, and A. Prakash. 2015.** Distribution of invasive European bird cherry (*Prunus padus*) in riparian forests along urban Alaska streams. In: FS-R10-FHP. 2015. Forest Health Conditions in Alaska 2014. Juneau, Alaska. USDA Forest Service, Alaska Region. Publication R10-PR-XXX. Xx pages.

Author abstract. Invasive species are a concern worldwide as they can displace native species, reduce biodiversity, and disrupt ecological processes. European bird cherry (Prunus padus) (EBC) is an invasive ornamental tree that is rapidly spreading and possibly displacing native trees along streams in parts of urban Alaska. This essay describes the current distribution of EBC along two Anchorage streams, Campbell and Chester creeks. We found EBC to be widespread within riparian forests along Campbell and Chester creeks. Our surveys along these streams observed the current populations of EBC to be primarily growing within the understory of riparian forests, distributed within the urban extents of these watersheds.

◆ **Saltmarsh, D.M. 2012.** Distribution and abundance of exotic earthworms (Oligochaeta: Lumbricidae) within the Kenai National Wildlife Refuge in Southcentral Alaska. Unpubl. M.S. Thesis, Alaska Pacific University, Anchorage, AK. 33 pp.

Author abstract. Exotic earthworms (Oligochaeta: Lumbricidae) have well-documented negative effects on forest ecosystems such as decreasing organic matter in the soil and reducing plant species richness. However, little is known about exotic earthworms in Alaska. This study seeks to document the distribution and possible limitations by soil pH and moisture for exotic earthworms within the Kenai National Wildlife Refuge (KNWR) in southcentral Alaska. We sampled a total of 70 sites near popular fishing areas, along road corridors, and in low human impact areas. Nearly all road sites (90%) and boat launches (80%) contained earthworms, while half (50%) of low human impact sites were occupied. Distance to roads was the only significant factor in predicting earthworm occurrence; soil pH, soil moisture, leaf litter depth, and vegetation cover were not significant predictors. These results suggest that road construction and use, as well as bait abandonment may be mechanisms of earthworm introduction within the KNWR.

◆ **Sanderson, L.A., J.A., McLaughlin, and P.M. Antunes. 2012.** The last great forest: a review of the status of invasive species in the North American boreal forest. Forestry (2012) 85 (3): 329-340. doi: 10.1093/forestry/cps033

Author abstract. The boreal forest is the world's largest terrestrial biome, covering all continents in the northern hemisphere. Much research has focused on the effects of forest management and climate change on biodiversity and ecosystem level processes of the boreal forest. However, even though climate change and the increasing rate of resource exploitation are likely to intensify the arrival and establishment of exotic species with the potential to become invasive, the boreal forest continues to be viewed as inhospitable to incoming species and we have little understanding of its invasive species status. We reviewed the literature and compiled information on the current status of invasive species across all taxa present in the North American boreal forest. We found that an increasing number of exotic plants, insects, earthworms, slugs and pathogens are establishing in the boreal forest. Research is scarce and their ecological effects are poorly understood. However, given that some of the reported species represent a major driver of change in many ecosystems globally, we expect that this review will provide direction for invasive species research as well as preventative measures aimed at better understanding and conserving Earth's largest terrestrial biome.

◆ **Schrader, B. and P. Hennon (compilers). 2005.** Assessment of invasive species in Alaska and its national forests. Unpublished administrative paper. USDA Forest Service, Alaska Region, Juneau, Alaska. 26 p.

Author summary. This document assesses the current status of invasive species in Alaska's ecosystems, with emphasis on the State's two national forests. Lists of invasive species were developed in several taxonomic groups including plants, terrestrial and aquatic organisms, tree pathogens and insects. Sixty-three plant species have been ranked according to their invasive characteristics. Spotted knapweed, Japanese knotweed, reed canarygrass, white sweetclover, ornamental jewelweed, Canada thistle, bird vetch, orange hawkweed, and garlic mustard were among the highest-ranked species. A number of non-native terrestrial fauna species have been introduced or transplanted in Alaska. At this time only rats are considered to be causing substantial ecological harm. The impacts of non-native slugs in estuaries are unknown, and concern exists about the expansion of introduced elk populations in southeast Alaska. Northern pike represents the most immediate concern among aquatic species, but several other species (Atlantic salmon, Chinese mitten crab, and New Zealand mudsnail) could invade Alaska in the future. No tree pathogen is currently damaging Alaska's native tree species but several fungal species from Europe and Asia could cause considerable damage if introduced. Four introduced insects are currently established and causing defoliation and tree mortality to spruce, birch, and larch. The results of this assessment will be used to develop a strategy to manage invasive species by applying the principles of prevention, early detection, control, and rehabilitation in cooperation with different agencies and partners throughout Alaska.

◆ **Sjoberg, K. and K. Danell. 2001.** Introduction of lodgepole pine in Sweden — ecological relevance for vertebrates. Forest Ecology and Management 141(1-2):143-153.

Author abstract. Several factors like vegetation structure, quality of food and protection from predators influence habitat utilisation by vertebrates. When an exotic tree species is introduced it has the potential to affect vertebrates in a number of ways. In the boreal region of Sweden (where Scots pine (*P. sylvestris*) and Norway spruce (*Picea abies*) are the dominant native conifers), lodgepole pine (*Pinus contorta*) was introduced on a large scale about 40 years ago.
Our review of current knowledge on the lodgepole pine suggests that, in general, vertebrates seem to utilise the different parts of the introduced lodgepole pine tree in the same way as they do the parts of Scots pine. However, to some extent they react to differences between the two pine species in needle morphology and chemical composition, bark structure, branch and canopy structure, as well as to differences between understory development in lodgepole and Scots pine plantations as a result of shading and soil pH. Today, we still lack knowledge about to what extent vertebrates use the seeds in lodgepole pine's serotinous cones (with their smaller size and darker colour). Effects on vertebrates are also expected to depend on such factors as the acreage the lodgepole pine will cover, and the distribution or patchiness of the stands. We conclude that bird species composition is relatively similar for pine stands of both species, at least at young age of the stands (i.e. the avian community seems to respond to differences in tree height and canopy density rather than to pine species). In addition, there may also be a temporal dimension involved. To what extent can an animal species with a life history adapted to the native tree species utilise the new habitat created by the introduced exotic tree species? What time is needed for this adjustment? In this paper, we discuss some of these aspects with examples from mammals and birds in the boreal forest.

◆ **Spellman, K.V., C.P.H. Mulder, and T.N. Hollingsworth. 2014.** Susceptibility of burned black spruce (Picea mariana) forests to non-native plant invasions in interior Alaska. Publ. online Jan. 5, 2014. Biol. Invasions. DOI 10.1007/s10530-013-0633-6.

Author abstract. As climate rapidly warms at high-latitudes, the boreal forest faces the simultaneous threats of increasing invasive plant abundances and increasing area burned by wildfire. Highly flammable and widespread black spruce (Picea mariana) forest represents a boreal habitat that may be increasingly susceptible to non-native plant invasion. This study assessed the role of burn severity, site moisture and time elapsed since burning in determining the invisibility of black spruce forests. We conducted field surveys for presence of non-native plants at 99 burned black spruce forest sites burned in 2004 in three regions of interior Alaska that spanned a gradient of burn severities and site moisture levels, and a chronosequence of sites in a single region that had burned in 1987, 1994, and 1999. We also conducted a greenhouse experiment where we grew invasive plants in vegetation and soil cores taken from a subset of these sites. In both our field survey and the greenhouse experiment, regional differences in soils and vegetation between burn complexes outweighed local burn severity or site moisture in determining the invisibility of burned black spruce sites. In the greenhouse experiments using cores from the 2004 burns, we found that the invasive focal species grew better in cores with soil and vegetation properties characteristic of low severity burns. Invasive plant growth in the greenhouse was greater in cores from the chronosequence burns with higher soil water holding capacity or lower native vascular biomass. We concluded that there are differences in susceptibility to non-native plant invasions between different regions of boreal Alaska based on native species regeneration. Reestablishment of native ground cover vegetation,

including rapidly colonizing bryophytes, appear to offer burned areas a level of resistance to invasive plant establishment.

◆ **Sykes, M.T. 2001.** Modelling the potential distribution and community dynamics of lodgepole pine (*Pinus contorta* Dougl. ex. Loud.) in Scandinavia. Forest Ecology and Management 141(1-2): 69-84.

Author abstract. Lodgepole pine is a native species of the Rocky Mountain and Pacific coast regions of North America. It is an ubiquitous species with a wide ecological amplitude growing under a variety of climatic conditions. It is among a number of northwestern species, others include for example Sitka spruce and Douglas Fir, that have been planted in a number of areas in Europe including Scandinavia.

The introduction of exotic species raises a number of questions about impacts on the native flora and fauna and when this is coupled with changing external forcing mechanisms such as a potentially rapid climate change, then it is necessary to examine even more carefully these introductions. Some of the questions raised, however, can only be addressed satisfactorily by predictive modelling.

The bioclimatic model STASH uses a small number of physiologically important climatic parameters to predict species distributions. It described quite accurately the native distribution, in North America, of two subspecies of lodgepole pine, the coastal *contorta* and the inland *latifolia*. The climate parameters derived from this exercise were used to predict the potential present distribution in Europe and a future potential distribution based on a greenhouse gas induced climate scenario from the Hamburg ECHAM3 climate model. Clear differences existed both between the two subspecies and between the responses to present and future European climates.

The climate parameters derived were also used to predict Scandinavian forest dynamics through the next 100 years of climate change, using the forest landscape model FORSKA 2. Two different outputs from the Hamburg climate model and the Hadley Centre model were used in this exercise. A number of simulations were carried out including lodgepole being planted at the beginning of a cycle and arriving later in the succession. Simulations showed that lodgepole pine is a good competitor with the native pine in both north and middle Sweden. Invasion into sites outside plantation areas is clearly possible from the model results in disturbed areas and this becomes more likely as a response to climate change. In non-disturbed areas invasion is minimal under the present climate, however, it is an increasing possibility with climate change even in old growth forests.

◆ **Taylor, K., T. Brummer, M.L. Taper, A. Wing, and L. J. Rew. 2012.** Human-mediated long-distance dispersal: an empirical evaluation of seed dispersal by vehicles. Diversity and Distributions. 1–10.

Author abstract. Aim: To determine seed retention rates on vehicles as a function of distance driven, road surface, weather condition and seed location on the vehicle undercarriage.
Location: Montana, United States.

Methods: Metal plates were covered with a seed-soil slurry, dried and attached to different locations underneath a vehicle. The vehicle was then driven on paved and unpaved roads under both wet and dry conditions. Plates were removed from the vehicle at seven distances between 4 and 256 km. The number of seeds remaining was determined. Four general models were assessed to explain observed seed retention.

Results: Under dry conditions, seed retention rates were high on both unpaved and paved roads, with 86–99% of the seeds remaining at 256 km. Under wet conditions, lower rates of seed retention were observed for both road surfaces: 0.3–80% of seeds were retained at 256 km on paved wet roads and 50–96% of seeds were retained at 256 km on unpaved wet roads. Plate location had a significant effect on seed retention under certain road surfaces and conditions, with loss generally being highest from the wheel wells. Of the statistical models compared, a double exponential model explained the most variation in seed retention.

Main conclusions: Vehicles act as vectors of long-distance dispersal. Seed adhered to vehicles can be retained for hundreds of kilometres under dry conditions. When wet conditions occur, a greater proportion of seeds will be dispersed shorter distances. Consequently, vehicle seed dispersal has implications for plant invasions and species migration rates, and those concerned with prevention and control of non-native plant invasions should consider vehicle seed transport when developing management strategies and plans.

◆ **Villano, K.L. 2008.** Wildfire burn susceptibility to non-native plant invasions in black spruce forests of Interior Alaska. Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 101 pp.

Author abstract. As the climate changes, Alaska's boreal forest faces the simultaneous threats of rising invasive plant abundances and increasing area burned by wildfire. Highly flammable and widespread black spruce forest represents a boreal habitat that may be increasingly susceptible to non-native plant invasion. In other biomes, non-native plant invasions are generally greatest in high severity burns that are only a few years old. The relationship between fire and non-native plant invasion has not been investigated in the northern boreal forest. To assess the invasibility of burned black spruce forests, I used burned field sites that spanned a gradient of burn severities, moisture levels, and burn ages. I conducted both field surveys and a greenhouse experiment using soil taken from burn sites. Contrary to generalizations from other biomes, I found soils from low severity burns and burns between 10 and 20 years old support greater invasive plant growth in black spruce forests than do high severity and more recent burns. In addition, regional differences between burn complexes outweighed burn severity and site moisture in determining the invasibility of burned black spruce sites. Finally, rebounding native vegetation appears to offer burned areas a level of resistance to invasive plant establishment.

◆ **Ware, C., D.M. Bergstrom, E. Müller, and I.G. Alsos. 2012.** Humans introduce viable seeds to the Arctic on footwear. Biol. Invasions (2012) 14:567–577 DOI 10.1007/s10530-011-0098-4

Author abstract. Expanding visitation to Polar regions combined with climate warming increases the potential for alien species introduction and establishment. We quantified vascular plant propagule pressure associated with different groups of travelers to the high-Arctic archipelago of Svalbard, and evaluated the potential of introduced seeds to germinate under the most favorable average Svalbard soil temperature (10_C). We sampled the footwear of 259 travelers arriving by air to Svalbard during the summer of 2008, recording 1,019 seeds: a mean of 3.9 (±0.8) seeds per traveler. Assuming the seed influx is representative for the whole year, we estimate a yearly seed load of around 270,000 by this vector alone. Seeds of 53 species were identified from 17 families, with Poaceae having both highest diversity and number of seeds. Eight of the families identified are among those most invasive worldwide, while the majority of the species identified were nonnative to Svalbard. The number of seeds was highest on footwear that had been used in forested and alpine areas in the 3 months prior to traveling to Svalbard, and increased with the amount of soil affixed to footwear. In total, 26% of the collected seeds germinated under simulated Svalbard conditions. Our results demonstrate high propagule transport through aviation to highly visited cold-climate regions and isolated islands is occurring. Alien species establishment is expected to increase with climate change, particularly in high latitude regions, making the need for regional management considerations a priority.

Section 9
CLIMATE CHANGE AND ASSISTED MIGRATION

SUMMARY

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Boreal ecosystems are inherently dynamic, and when it comes to Regions II and III, change is the only constant. Climate change has and will impact all aspects of forest regeneration, from productivity and growth rate to species composition (including invasives) to efficacy of site prep. Climate is a direct driver of fire and insect disturbances.

Paleoecological evidence shows that the geographic ranges of forests have expanded and contracted multiple times over the past ice ages (Hamrick 2004). Therefore, we know that forest species are capable of long-range dispersal and continental-scale migration. It is natural for species assemblages to re-sort in response to changes in climate. Although we relate to spruce-dominated forests, the paleo record (proxies include fossil pollen, tree rings, DNA) shows that the spruce dominated forests as we know them are relatively recent (5 – 8 thousand years ago; Ager 2001; Barber 2002; Anderson et al. 2006; Finkenbinder et al. 2014) and that current treeline may have reached its altitude in the past 2500 years (Alden 1987). The early Holocene (~10 – 7.5 thousand years ago) was warmer and drier than today and can inform our projections of future forest/fire/climate dynamics (Anderson et al. 2006). Likewise, comparing how forests have responded to recent, e.g., past 100 years, warming trends (Barber 2000; Barber et al. 2002; Barber 2002) can improve our understanding of both current forest health and identify future vulnerabilities.

These documented impacts of climate change forests provide evidence that Regions II and III forests are departing from historical baseline conditions. For example, growing season is increasing (Wendler & Shulski 2009), productivity is declining in upland, lowland and valley bottoms (Beck et al. 2011; Baird et al. 2012), and in particular on south-facing slopes (Juday et al. 1998), believed to be caused by temperature-induced drought stress (Juday et al. 2003; Hogg et al 2005; Berg et al. 2009; Beck et al. 2011, Juday et al. 2012, Walker & Johnstone 2014). In addition to reduced growth of dominant species, plant disease and insect outbreaks, warming and thawing of permafrost, wetland drying, increased wildfire, and increased postfire recruitment of deciduous trees has been observed in recent decades (Williamson et al. 2009; Chapin et al. 2010; Wolken et al. 2012). Observed trends in treeline and ecotone dynamics, however, suggest range expansion at both latitudinal and altitudinal treeline (Juday et al. 1999; Danby & Hik 2007; Dial et al 2007; Tape 2011; Conway & Danby 2014), but also that treeline changes will likely vary over time and space (Lloyd et al. 2002; Juday et al. 2003).

Both climate change and economic development are accelerating at a rapid pace throughout both regions, accelerating the already documented changes, placing burdens on communities and infrastructure, and placing risk on regional socio-economics (Burton et al. 2010). It is widely accepted that some species and some populations within species will benefit from directional changes in climate, whereas others will decline. Which species or populations will be successful depends on multiple factors including phenotypic plasticity, including physiological acclimation (Robertson 2012), phenology (Robertson 2012; Mann et al. 2014), and evolutionary history/ genetic variation (Keller et al. 2011). Plasticity is important for trees to withstand projected increases in climate variability, although there are clear thresholds to acclimation responses (Lloyd et al. 2013). Not surprisingly, stressed forest stands are the most vulnerable to disturbance and climate-related impacts. Information on stand growth prior to fire or other disturbances is a useful predictor of at-risk stands (Johnstone et al. 2010c).

Potential management actions to increase the resilience of our forests to climate change include reducing non-climatic stressors, reducing sensitivity to climate change, and/or maintaining or enhancing adaptive capacity in the both biophysical parameters and in the institutions that manage forests (Young & Ogden 2010; Peterson et al. 2011; Gauthier et al.2014). Suggested management actions include:

- Altered silviculture practices for climate change such as shorter rotation periods, use of exotics and fast-growing species (Johnston et al. 2009), and site prep designed to mitigate the effects of climate change (e.g., reduce drought stress to increase seedling height growth; Cortini et al. 2011). As trees are long-lived, many populations may be inherently resilient to climate change; however, certain life history stages (e.g., seedlings) may be particularly vulnerable (Johnstone et al. 2010c). Particular attention to vulnerable life stages may buy time for other management activities to be identified or accepted;
- Improve tree breeding to increase plasticity and ensure better fit with future climates (Johnston et al. 2009);
- Use scenario planning to identify the range of future landscape conditions and management intervention points (Fresco 2012);
- Reduce non-climate stressors (Gauthier et al. 2014);
- Study and monitor thresholds or tipping points (Price et al. 2013);
- Adopt adaptive management frameworks (Gauthier et al. 2014). Regardless of strategy, Price et al. (2013) point to the need for creativity and ingenuity among forest practitioners and researchers to develop effective adaptation strategies;
- Assisted migration (see below).

Tree populations or forest stands are considered to be 'locally adapted' when populations have higher fitness in their home sites than they do if planted elsewhere in the species' range. Local adaptation has been long-considered in reforestation practices where local stock has been selected for replanting (Hamrick 2004; Aitken et al. 2008; Keller et al. 2011). A directionally changing climate means that local populations may be adapted to historical climate and not best suited for current and/or future climates (Robertson 2012). This maladaptation can result in lower productivity and increased susceptibility to pests and other disturbances (Aitken et al. 2008; Johnstone et al. 2009). As evidenced from the paleo record, boreal and temperate tress have the ability to track climate niches over long distances, however, the projected rate and magnitude of projected 21st century change is expected to outpace the migration rate for many species (Leech et al. 2011). Assisted migration is a proactive management alternative to assist species and populations to mimic natural migration to climatically-suitable habitats (Johnston et al. 2009) and is based on decades of research in provenance trials (Aitken et al. 2008; Leech et al. 2009; Thomson et al. 2009).

There are generally two types of assisted migration which are often confused. Often, assisted migration is associated with moving species beyond their current range boundaries (Pedlar et al. 2012). This can include reforesting with species found farther south that are 'pre-adapted' to warmer and longer growing seasons, e.g., reforesting with lodgepole pine in Region III. It can also focus on movement of narrowly distributed threatened species outside their current range boundaries. Although this is controversial, we have learned from the paleo record that long-distance species migrations are typical over geologic time, and it may be a last-ditch effort to save some species or ecosystem services. Less controversial is the movement among populations within their native ranges (Pedlar et al. 2012). For example, reforestation with mixed stock from various latitudinal origins sampled from across a species' range allows the best-fit genotypes to the local climate regime to be the most successful (Ukrainetz et al. 2011; Robertson 2012). Other environmental parameters besides climate, however, need to be considered for seedling survival, including soil type and microbial composition (Kranabetter et al. 2012; Gundale et al. 2014), photoperiod and range of climate variability (Robertson 2012).

REFERENCES

◆ **Ager, T.A. 2001.** Holocene vegetation history of the northern Kenai Mountains, south-central Alaska. Pages 91-107 in Geologic studies in Alaska by the United States Geological Survey, 1999. L. Gough and R. Wilson (editors). United States Geological Survey, Professional Paper 1633. Denver, Colorado. 142 p.

Author abstract. Analysis of pollen assemblages from a 103-cm-thick peat deposit exposed near Tern Lake, Kenai Peninsula, Alaska, provides the first radiocarbon-dated postglacial vegetation history for the Kenai Mountains. The peat overlies glacial till deposited during the late Wisconsin glaciation. **A** peat sample from near the base of the deposit provides a radiocarbon age of 9,3 lot200 yr B.P., the first minimum age for deglaciation of the interior valleys of the Kenai Mountains. Earliest postglacial vegetation recorded at this site was composed of shrub birch (Betula nana), alder (Alnus), willow (Salix), grasses (Poaceae), wormwood (Artemisia), various herbs, and ferns (Polypodiaceae type). Another common shrub in this early postglacial vegetation was soapberry (Shepherdia canadensis), a shrub now uncommon on the Kenai Peninsula. Between about 8,600 and 7,800 yr B.P., soapberry shrubs were abundant in the area, along with ferns and alders. Soon after that, the alder population increased rapidly, soapberry shrubs diminished in importance, and boreal spruce (probably white spruce, Picea glauca) began to invade the western portals of the major valleys. The boreal spruce spread eastward into the mountain valleys from the northern Kenai Lowlands, probably along with paper birch trees (Betula papyrifera). By about 5,600 yr B.P., if not earlier, boreal spruce trees were colonizing the Tern Lake area. By about 2,900 yr B.P., small but significant amounts of pollen of mountain hemlock (Tsuga mertensiana) began appearing in the pollen assemblages at this site, and soon thereafter, spruce pollen percentages increased substantially. This rise in spruce and mountain hemlock pollen percentages probably reflects the colonization of the eastern and northern valleys of the Kenai Mountains by Sitka spruce (Picea sitchensis) and mountain hemlocks from sources in Prince William Sound to the east. The local vegetation seen in the Tern Lake area today developed within the past ca. 2,500 years. This vegetation is a rich mixture of boreal, (interior continental climate) and coastal-adapted (maritime climate) tree, shrub, and herb species. This blending of interior and coastal floras reflects a rather abrupt transitional boundary near Tern Lake between the maritime climate of the eastern and southern coasts of the Kenai Peninsula, and the more continental climate of the Kenai Lowland and northwestern Kenai Mountains. Many boreal plant species reach their easternmost range on the Kenai Peninsula near Tern Lake, and their further expansion appears to be limited by maritime climate near the coast.

◆**Aitken, S.N., S. Yeaman, J.A. Holliday, T. Wang, S. Curtis-McLane. 2008.** Adaptation, migration or extirpation: climate change outcomes for tree populations. Evolutionary Applications **1**(1): 95-111.

Author abstract. Species distribution models predict a wholesale redistribution of trees in the next century, yet migratory responses necessary to spatially track climates far exceed maximum post-glacial rates. The extent to which populations will adapt will depend upon phenotypic variation, strength of selection, fecundity, interspecific competition, and biotic interactions. Populations of temperate and boreal trees show moderate to strong clines in phenology and growth along temperature gradients, indicating substantial local adaptation. Traits involved in local adaptation appear to be the product of small effects of many genes, and the resulting genotypic redundancy combined with high fecundity may facilitate rapid local adaptation despite high gene flow. Gene flow with preadapted alleles from warmer climates may promote adaptation and migration at the leading edge, while populations at the rear will likely face extirpation. Widespread species with large populations and high fecundity are likely to persist and adapt, but will likely suffer adaptational lag for a few generations. As all tree species will be suffering lags, interspecific competition may weaken, facilitating persistence under suboptimal conditions. Species with small populations, fragmented ranges, low fecundity, or suffering declines due to introduced insects or diseases should be candidates for facilitated migration.

◆ **Alden, J.N. 1987**. Genetic diversity and population structure of picea glauca on an altitudinal gradient in Interior Alaska. Can. J. For. Res., 17(12): 1519-1526, 10.1139/x87-234.

Author abstract. Allozyme variation at 13 loci for 11 enzyme systems was studied in four white spruce (*Picea glauca* (Moench) Voss) populations extending from a floodplain at 120 m above sea level to the altitudinal tree limit at 750 m above sea level in interior Alaska. Although 97% of the total genetic diversity was among trees within stands and 1% was among stands within populations, frequencies of several allozymes and allozyme genotypes were significantly different ($P < 0.05$) among populations. Ninety-two percent of the loci were polymorphic. Total heterozygosity was 0.276. Heterozygosity and allozyme frequencies were not related to altitude. The population at the tree limit was as genetically diverse as populations at low elevations ($\bar{H}_e = 0.269$) and contained four of seven rare alleles observed in all populations. These observations suggested that white spruce is genetically diverse in interior Alaska and the tree-limit population will continue to colonize new habitats. Genetic distance was not related to altitude and geographic distance and was less between the tree-limit and upper slope populations than among other populations. A detectable gene substitution rate was estimated at 10^{-6} per year. Populations on the upper slope and at the tree limit may have diverged about 2500 years ago and reached tree-limit altitudes only recently. Populations at low altitudes may have diverged during early Holocene white spruce expansion. We concluded that white spruce is genetically diverse in a small geographic area in interior Alaska. Results suggested that local white spruce populations should be regenerated from indigenous seed and that provenance research is needed to support afforestation programs.

◆ **Anderson, R.S., D.J. Hallett, E.E. Berg, R. B. Jass, J.L. Toney, C. S. De Fontaine, A. De Volder. 2006.** Holocene development of boreal forests and fire regimes on the Kenai Lowlands of Alaska. The Holocene 16(6):791-803.

Author description. Several studies have noted a relationship between vegetation type and fire frequency, yet despite the importance of ecosystem processes such as fire the long-term relationships between disturbance, climate and vegetation type are incompletely understood. We analysed pollen, plant macrofossils and sedimentary charcoal from three lakes within the Kenai lowlands to determine postglacial relationships between disturbance, climate and vegetation for the Boreal forest of southwest Alaska. An herb tundra was established in the lowlands following deglaciation by 13 000 cal. BP. Salix, Alnus and probably Betula kenaica, expanded in the area after 10 700 cal. BP, followed by Picea glauca by 8500 cal. BP. Picea mariana became established by 4600 cal. BP. The early Holocene was probably the driest time during the postglacial, as determined by aquatic plant macrofossils and climate models. Lake levels reached near-modern conditions by at least 8000 cal. BP. Mean Fire Intervals (MFI) were longest during the shrub-herb tundra phase (138+/-65 yr), decreased after expansion of B. kenaica, Salix and Populus (77+/-49 yr) and Picea glauca (81+/-41 yr), and increased again with the arrival of P. mariana (130+/-66 yr). Unlike previous studies, our data demonstrate the highest fire frequencies during the early to mid-Holocene and less frequent fire during the late Holocene when P. mariana forests dominated the lowlands. Early Holocene forests of P. glauca and B. kenaica existed in summers that were longer and drier than today, while the increasingly wetter and cooler climates of the late Holocene probably hindered forest fire around Paradox Lake, perhaps because of less frequent summer drought.

◆ **Baird, R.A., D. Verbyla, and T.N. Hollingsworth. 2012.** Browning of the landscape of interior Alaska based on 1986-2009 Landsat sensor NDVI. Canadian Journal of Forest Research, 2012, 42(7): 1371-1382, 10.1139/x2012-088

Author abstract. We used a time series of 1986–2009 Landsat sensor data to compute the Normalized Difference Vegetation Index (NDVI) for 30 m pixels within the Bonanza Creek Experimental Forest of interior Alaska. Based on simple linear regression, we found significant ($p < 0.05$) declining trends in mean NDVI of three dominant landscape types of floodplains, lowlands, and uplands. At smaller patch sizes, similar declining trends occurred among topographic classes of north- and south-facing slopes and valley bottoms and among forest classes, including black spruce (*Picea mariana* (Mill.) B.S.P.). Significant positive trends in mean NDVI occurred only in areas that were recently burned, whereas wetlands had no significant trend. The greatest departure from the NDVI trend line occurred following the 2004 drought for all forest classes except black spruce, which dominates the coldest sites, and balsam poplar (*Populus balsamifera* L.), which occurs on low, moist terraces within the Tanana River floodplain. The consistent long-term declining trend at several spatial scales may be due to a regional climatic regime shift that occurred in the mid-1970s.

◆ **Barber, V.A. 2002.** Millennial to annual scale paleoclimatic change in central Alaska during the late quaternary interpreted from lake sediments and tree rings. Ph.D. Dissertation. University of Alaska Fairbanks. Fairbanks, AK, USA. 131 pp.

Author abstract: The theme of this dissertation is the importance of effective moisture (precipitation minus evaporation) in subarctic ecosystems. Interior Alaska has a relatively dry climate with annual precipitation ranging from 25-45 cm. Records from interior Alaska lake sediment cores show low lake levels following the Last Glacial Maximum, with significant increases at 12,000 and 9,000 14C years B.P. Using lake-level reconstructions and models based on modern hydrologic and meteorologic data, we infer precipitation of 35-75% less than modern at 12,000 yr. BP, 25-45% less than modern at 9,000 yr. BP, and 10-20% less than modern at 6,000 yr. BP. Trees were scarce on the interior Alaskan landscape during the late Pleistocene with birch species appearing about 12,000 BP and spruce species approximately 3500 years later. The correspondence between lake-level and vegetation changes suggests that moisture may have been one of the limiting factors in the establishment of these tree species. Alaska climate records show a climatic regime shift in the mid-1970s. Less effective moisture is available over the past 30 years because summer temperatures in interior Alaska have been increasing without a concurrent increase in precipitation. Radial growth of white spruce at 20 low elevation stands in interior Alaska declined corresponding with this climatic change. The observation that moisture limits spruce growth in Alaska today is consistent with our inference of moisture limitation in the early Holocene. A 200-year reconstruction was developed based on two tree ring proxies, 13C discrimination and maximum latewood density, which together show excellent agreement with the recorded Fairbanks average May through August temperatures. The first half of the 20th century is characterized by the coolest summers of the 200 year period of reconstruction, while the latter part of the 20th century, particularly from 1974 onward, is characterized by some of the warmest summers of the 200 year period. Mid-19th century summer temperatures reconstruct to be as warm as the latter part of the 20th century, which is inconsistent with reconstructions of other regions. It seems likely, based on current information, that these inconsistencies may be real and may reflect regional synoptic conditions unique to interior Alaska. Distinctive decadal scale regimes were identified throughout the record.

◆ **Barber, V. A., G. P. Juday and E. Berg. 2002.** Assessment of recent and possible future forest responses to climate in boreal Alaska. Pages 102-105 plus 3 figures (pp 288-289) in Workshop on Northern Timberline Forests: Environmental and Socio-economic Issues and Concerns. Finnish Forest Research Institute. Kolari Research Station. 289 pp.

Compiler abstract. This paper summarizes climatic conditions in boreal Alaska, and shifts in forest vegetation that have or are likely to accompany climate change. In central Alaska, low elevation upland white spruce trees are consistent in their negative growth response to temperature. Interior lowland white spruce trees are generally not limited by moisture stress and respond positively to temperature. Black spruce trees growing on permafrost in interior Alaska respond negatively to April/May or June temperature. Alpine tree populations display both positive and negative responses to summer warming. Based on temperatures predictions and growth models based on temperature, much of the white spruce in interior Alaska will be eliminated by about 2080. Black spruce should a slower decline in growth, but its demise is expected to accelerate with increased thermokarsting as permafrost melts and habitat is lost.

◆ **Barber, V.A., G.P. Juday and B.P. Finney. 2000.** Reduced growth of Alaskan white spruce in the twentieth century from temperature-induced drought stress. Nature 405:668-673.

Author abstract. The extension of growing season at high northern latitudes seems increasingly clear from satellite observations of vegetation extent and duration1,2. This extension is also thought to explain the observed increase in amplitude of seasonal variations in atmospheric CO2 concentration. Increased plant respiration and photosynthesis both correlate well with increases in temperature this century and are therefore the most probable link between the vegetation and CO2 observations3. From these observations1,2, it has been suggested that increases in temperature have stimulated as a whole4. Here we present multi-proxy tree-ring data (ring width, maximum late-wood density and carbon-isotope composition)
from 20 productive stands of white spruce in the interior of Alaska. The tree-ring records show a strong and consistent relationship over the past 90 years and indicate that, in contrast with earlier predictions, radial growth has decreased with increasing temperature. Our data show that temperature-induced drought stress has disproportionately affected the most rapidly growing white spruce, suggesting that, under recent climate warming, drought may have been an important factor limiting carbon uptake in a large portion of the North American boreal forest. If this limitation in growth due to drought stress is sustained, the future capacity of northern latitudes to sequester carbon may be less than currently expected.

◆ **Barber, V.A., G.P. Juday, B.P. Finney and M. Wilmking. 2004.** Reconstruction of summer temperatures in interior Alaska from tree-ring proxies: evidence for changing synoptic climate regimes. Climatic Change 63:91-121.

Abstract. Maximum latewood density and δ13C discrimination of Interior Alaska white spruce were used to reconstruct summer (May through August) temperature at Fairbanks for the period 1800–1996, one of the first high-resolution reconstructions for this region. This combination of latewood density and δ13C discrimination explains 59.9% of the variance in summer temperature during the period of record 1906–1996. The 200-yr. reconstruction is characterized by 7 decadal-scale regimes. Regime changes are indicated at 1816, 1834, 1879, 1916, 1937, and 1974, are abrupt, and appear to be the result of synoptic scale climate changes. The mean of summer temperature for the period of reconstruction (1800–1996) was 13.49 ◦C. During the period of instrument record (1903–1996) the mean of summer temperature was 13.31 ◦C for both the reconstruction and the recorded data. The coldest interval was 1916–1937 (12.62 ◦C) and the warmest was 1974–1996 (14.23 ◦C) for the recorded data. The reconstruction differs from records of northern hemisphere temperatures over this period, especially because of Interior Alaska warm periods reconstructed from 1834 to 1851 (14.24 ◦C) and from 1862 to 1879 (14.19 ◦C) and because of the cool period in the early part of the 20th century (1917–1974). We show additional tree ring data that support our reconstruction of these warm periods. Alternate hypotheses involving autogenic effect of tree growth on the site, altered tree sensitivity, or novel

combinations of temperature and precipitation were explored and while they cannot be ruled out as contributors to the anomalously warm 19th century reconstruction, they were not supported by available data. White spruce radial growth is highly correlated with reconstructed summer temperature, and temperature appears to be a reliable index of carbon uptake in this system.

◆ **Barber, V.A., G.P. Juday, T. Osterkamp, R. D'Arrigo, E. Berg, B. Buckley, L. Hinzman, H. Huntington, T. Jorgensen, A.D. McGuire, B. Riordan, A. Whiting, G. Wiles, and M. Wilmking. 2009.** A synthesis of recent climate warming effects on terrestrial ecosystems in Alaska. Chapter 9 in Climate Warming in Western North America: Evidence and Environmental Effects (Edited by F. Wagner), pp. 110-139. University of Utah Press. Salt Lake City, Utah.

Author abstract. The instrument-based climate record in Alaska displays a strong late-twentieth century warming. Climate in Alaska also displays a record of sudden regime shifts. Precipitation there is highly variable and shows no strong trends. Effective moisture (P-PET), however, has decreased, resulting in widespread shrinkage and drying of lakes and ponds in the regions of low or moderate precipitation. Overall glacial mass balance is negative, and most show ice margin retreat, although some glacial systems are in positive mass balance. Permafrost is warming across the state, and ground subsidence associated with thawing of ice-rich permafrost is commonly observed. Since buildings and infrastructure, as well as natural disturbances, can cause warming of the permafrost, it is difficult to distinguish from climatic warming in some cases. The annual period of snow and ice cover is decreasing, and growing season is increasing in length with greater normalized difference vegetation index (NDVI) greenness in the tundra region. North of the Brooks Range, tall shrubs have advanced into the tundra, and warming experiments show that low shrub cover would significantly increase with additional warming. White spruce populations at treeline include trees that grow more with warming as well as others that grow less with warming. Major species in the boreal forest region also include populations with similar responses, but growth on many of the productive sites has declined. Recent high temperatures have caused widespread tree stress. Major outbreaks of tree-damaging insects have occurred due to both tree stress and direct temperature controls on insects. Millions of acres of beetle-killed trees on the Kenai Peninsula are a potential fire hazard. The extent of forest fires in Alaska is positively associated with specific temperature factors. These changes are confronting people with a variety of challenges, ranging from obtaining subsistence food and potable water to maintaining health and safety. Scenarios of future Alaska climate produced by general circulation models project significant future warming, which would exceed the apparent tolerance of some component species of current ecosystems.

◆ **Beck, P.S.A., G.P. Juday, C. Alix, V.A. Barber, S.E. Winslow, E.E Sousa, P. Heiser, J.D. Herriges, S.J. Goetz. 2011.** Changes in forest productivity across Alaska consistent with biome shift. Ecology Letters 14(4): 373-379.

Author abstract: Global vegetation models predict that boreal forests are particularly sensitive to a biome shift during the 21st century. This shift would manifest itself first at the biome’s margins, with evergreen forest expanding into current tundra while being replaced by grasslands or temperate forest at the biome’s southern edge. We evaluated changes in forest productivity since 1982 across boreal Alaska by linking satellite estimates of primary productivity and a large tree-ring data set. Trends in both records show consistent growth increases at the boreal–tundra

ecotones that contrast with drought-induced productivity declines throughout interior Alaska. These patterns support the hypothesized effects of an initiating biome shift. Ultimately, tree dispersal rates, habitat availability and the rate of future climate change, and how it changes disturbance regimes, are expected to determine where the boreal biome will undergo a gradual geographic range shift, and where a more rapid decline.

◆ **Berg, E.E., K.M. Hillman, R.Dial, A. DeRuwe. 2009.** Recent woody invasion of wetlands on the Kenai Peninsula Lowlands, south-central Alaska: a major regime shift after 18 000 years of wet *Sphagnum*–sedge peat recruitment. Canadian Journal of Forest Research, 2009, 39(11): 2033-2046, 10.1139/X09-121

Author abstract. We document accelerating invasion of woody vegetation into wetlands on the western Kenai Peninsula lowlands. Historical aerial photography for 11 wetland sites showed that herbaceous area shrank 6.2%/decade from 1951 to 1968, and 11.1%/decade from 1968 to 1996. Corresponding rates for converting herbaceous area to shrubland were 11.5% and 13.7%/decade, respectively, and, for converting nonforest to forest, were 7.8% and 8.3%/decade, respectively. Black spruce (Picea mariana (Mill.) BSP) forests on three wetland perimeters established since the Little Ice Age concluded in the 1850s. Dwarf birch shrubs at three wetland sites showed median apparent tree-ring age of 13 years, indicating recent shrub colonization at these sites. Peat cores at 24 wetland sites (basal peat ages 1840 – 18 740 calibrated years before present) indicated that these peatlands originated as wet Sphagnum–sedge fens with very little woody vegetation. Local meteorological records show a 55% decline in available water since 1968, of which one-third is due to higher summer temperatures and increased evapotranspiration and two-thirds is due to lower annual precipitation. These results suggest that wet *Sphagnum*–sedge fens initiating since the end of the Wisconsin glaciation began to dry in the 1850s and that this drying has greatly accelerated since the 1970s.

◆ **Burton, P.J.; Bergeron, Y.; Bogdanski, B.E.C.; Juday, G.P.; Kuuluvainen, T.; McAfee, B.J.; Ogden, A.E.; Teplyakov, V.K.; Alfaro, R.I.; Francis, D.A.; Gauthier, S.; Hantula, J. 2010.** Sustainability of boreal forests and forestry in a changing environment. Pages 249-282 Chapter 14 in G. Mery, P. Katila, G. Galloway, R.I. Alfaro, M. Kanninen, M. Lobovikov, and J. Varjo, editors. Forests and Society - Responding to Global Drivers of Change. International Union of Forest Research Organizations, Vienna, Austria, IUFRO World Series.

Author abstract. The circumpolar boreal forest is the fourth largest terrestrial biome on the planet. It is entering a period of relatively rapid transition, propelled by climate change and economic development. Warming conditions threaten to alter processes as diverse as permafrost retention, insect outbreaks, and transportation. Thawing permafrost and increased levels of natural and anthropogenic disturbance may result in net releases of carbon dioxide and methane, while forest cover with greater biomass can be expected to expand onto the arctic tundra. Human use in some parts of northern forests is becoming more centralised and industrialised, with cumulative impacts from hydroelectric development, the oil and gas sector, mining, timber harvesting, and transportation. Communities tend to be widely spaced, and are either highly dependent on resource-based commodity exports or on subsistence-based lifestyles supported by local biodiversity. Efforts are underway in many jurisdictions to curtail illegal logging and environmentally damaging industrial development, to account for non-timber forest values in the course of forest management, and to promote the economic diversification of communities. In order to preserve the integrity of ecosystem processes, efforts are being directed in some jurisdictions to better emulate natural disturbance regimes and forest structures in the implementation of ecosystem-based management. The ecosystems and people of the world's boreal forests are vulnerable to impending changes in climate and socio-economics, although regions within the biome differ markedly in their exposure to dramatic changes in climate and forest products markets and also in the adaptive capacity of communities and infrastructure. Despite the changes that can be expected, the boreal zone will continue to present opportunities to undertake land management over largely natural forests in a manner that respects the need for sustaining biodiversity, economically viable enterprises, and northern communities. If regional economies can diversify as well, such an advantage may also facilitate ecotourism and attractive lifestyle options in the circumboreal region.

◆ **Chapin, F.S., A.D., McGuire, R.W. Ruess, T.N. Hollingsworth, M.C. Mack, J.F. Johnstone, E.S. Kasischke, E.S. Euskirchen, J.B. Jones, M.T. Jorgenson, K. Kielland, G.P. Kofinas, M.R. Turetsky, J. Yarie, A.H. Lloyd, and D.L. Taylor. 2010.** Resilience of Alaska's boreal forest to climatic change. Canadian Journal of Forest Research, 2010, 40(7): 1360-1370, 10.1139/X10-074

Author abstract. This paper assesses the resilience of Alaska's boreal forest system to rapid climatic change. Recent warming is associated with reduced growth of dominant tree species, plant disease and insect outbreaks, warming and thawing of permafrost, drying of lakes, increased wildfire extent, increased postfire recruitment of deciduous trees, and reduced safety of hunters traveling on river ice. These changes have modified key structural features, feedbacks, and interactions in the boreal forest, including reduced effects of upland permafrost on regional hydrology, expansion of boreal forest into tundra, and amplification of climate warming because of reduced albedo (shorter winter season) and carbon release from wildfires. Other temperature-sensitive processes for which no trends have been detected include composition of plant and microbial communities, long-term landscape-scale change in carbon stocks, stream discharge, mammalian population dynamics, and river access and subsistence opportunities for rural indigenous communities. Projections of continued warming suggest that Alaska's boreal forest will undergo significant functional and structural changes within the next few decades that are unprecedented in the last 6000 years. The impact of these social–ecological changes will depend in part on the extent of landscape reorganization between uplands and lowlands and on policies regulating subsistence opportunities for rural communities.

◆ **Conway, A.J. and R.K. Danby. 2014.** Recent advance of forest–grassland ecotones in southwestern Yukon. CJFR 44(5): 509-520, 10.1139/cjfr-2013-0429.

Author abstract. We investigated recent ecotone dynamics in the forest-grassland mosaics of southwestern Yukon. Our objectives were to determine (*i*) if forests are encroaching into grasslands, (*ii*) if rate and extent of encroachment varies by region or with topographic setting, and (*iii*) if encroachment is related to climate change and variability. Dendroecological techniques were used to obtain dates of establishment for 1847 trees (trembling aspen (*Populus tremuloides* Michx.) and white spruce (*Picea glauca* (Moench) Voss)) sampled from 28 sites divided between two different regions and three topographic settings. Generalized linear modeling was used to identify relationships between climate and tree establishment. Results show that encroachment of forest, particularly aspen trees, into grasslands has been nearly ubiquitous on flat terrain and on south-facing slopes in both regions over the last 60–80 years. In contrast, spruce-dominated ecotones on north-facing slopes experienced little change. Aspen establishment was positively associated with spring temperatures and precipitation, although evidence suggests that other factors such as soil moisture interact with climate to mediate the timing and rate of tree encroachment. These results indicate that transformation of grasslands to aspen-dominated forest is an additional, but previously unexplored, element of the widespread ecosystem changes currently being experienced in northwestern North America.

◆ **Cortini, F., P. G. Comeau, J. O. Boateng, L. Bedford, J. McClarnon, and A. Powelson. 2011.** Effects of climate on growth of lodgepole pine and white spruce following site preparation and its implications in a changing climate. Canadian Journal of Forest Research 41:180-194.

Author abstract. Site preparation and vegetation control can be used to mitigate climate change effects on early plantation growth in boreal forests. In this study, we explored growth of lodgepole pine (Pinus contorta Dougl. ex Loud. var. latifolia Engelm.) and white spruce (Picea glauca (Moench) Voss) in relation to climate and site preparation using 20 years of data collected from studies in British Columbia. Results indicate that up to 45% of the variation in spruce growth and up to 37% of the variation in pine growth over this 20-year period can be explained by selected climatic variables. Monthly climate variables showed a stronger relationship to conifer growth than seasonal and annual variables. Climate variables related to the preceding year accounted for more than half of the variables in the final equations, indicating a lagged response in conifer growth. Future projections indicated that height growth of young lodgepole pine plantations in the subboreal zone could benefit (in the short term) from longer growing seasons by up to 12% on untreated stands. Untreated young white spruce plantations in the boreal zone may suffer height growth decreases of up to 10% due to increased drought stress. Vegetation control and mechanical site preparation treatments appear to mitigate effects of climate change to some extent.

◆ **Danby, R. K. and HIK, D. S. 2007.** Responses of white spruce (*Picea glauca*) to experimental warming at a subarctic alpine treeline. Global Change Biology, 13: 437–451. doi: 10.1111/j.1365-2486.2006.01302.x

Author abstract. From 2001 to 2004 we experimentally warmed 40 large, naturally established, white spruce [*Picea glauca* (Moench) Voss] seedlings at alpine treeline in southwest Yukon, Canada, using passive open-top chambers (OTCs) distributed equally between opposing north and south-facing slopes. Our goal was to test the hypothesis that an increase in temperature consistent with global climate warming would elicit a positive growth response. OTCs increased growing season air temperatures by 1.8°C and annual growing degree-days by one-third. In response, warmed seedlings grew significantly taller and had higher photosynthetic rates compared with control seedlings. On the south aspect, soil temperatures averaged 1.0°C warmer and the snow-free period was nearly 1 month longer. These seedlings grew longer branches and wider annual rings than seedlings on the north aspect, but had reduced Photosystem-II efficiency and experienced higher winter needle mortality. The presence of OTCs tended to reduce winter dieback over the course of the experiment. These results indicate that climate warming will enhance vertical growth rates of young conifers, with implications for future changes to the structure and elevation of treeline contingent upon exposure-related differences. Our results suggest that the growth of seedlings on north-facing slopes is limited by low soil temperature in the presence of permafrost, while growth on south-facing slopes appears limited by winter desiccation and cold-induced photoinhibition.

◆ **Dial, R.J., E.E. Berg, K. Timm, A. McMahon, and J. Geck. 2007.** Changes in the alpine forest-tundra ecotone commensurate with recent warming in southcentral Alaska: evidence from orthophotos and field plots. Journal of Geophysical Research, Volume 112, 15 p.

Author abstract. The complex response of the forest-tundra ecotone (FT) to climate change may not generalize well geographically. We document FT changes in a nonpermafrost region of southcentral Alaska during a known warming period. Using 1951 and 1996 orthophotos overlain on digital elevation models across 800 km^2 of the west Kenai Mountains, we identified cover classes and topography for 978 random points and the highest closed-canopy conifer patches along 205 random altitudinal gradients. Results show 29% of FT area increased in woodiness, with closed-canopy forest expanding 14%/decade and shrubs 4%/decade; unvegetated areas decreased 17.4%/decade and tundra 5%/decade. Area of open woodland remained constant but changed location. Timberline, estimated using both the 205 altitudinal gradients and the upper quartile elevations of closed-canopy forest among the 978 points, rose very little. Tree line, identified using upper quartiles of open woodland, rose ~50 m on cool, northerly aspects, but not on other aspects. Dendrochronology on high-elevation seedlings showed a congruence between decadal recruitment and regional changes in climate from 1945 to 2005. Patterns observed in the climatic FT of the Kenai Mountains corroborate other studies that show regional and landscape specificity of the structural response of FT to climate change. FT shifted upwards on cooler, presumably more mesic aspects near seed sources; however, on warm aspects the density of shrubs and trees increased, but FT did not rise. If current conditions continue for the next 50–100 years, the Kenai FT will markedly change to a far woodier landscape with less tundra and more closed-canopy forest.

◆ **Finkenbinder, M.S., M.B. Abbott, M.E. Edwards, C.T. Landon, B.A. Steinman, B.P. Phinney. 2014.** A 31,000 year record of paleoenvironmental and lake-level change from Harding Lake, Alaska. USA. Quat. Sci. Rev. 87 (2014) 98-113.

Author abstract: Physical and geochemical proxy analyses of sediment cores from Harding Lake in central Alaska are used to reconstruct paleoenvironmental change and millennial scale fluctuations in lake level for the last 31,000 years. We analyzed a composite 422 cm core from the lake depocenter (42.1 m water depth) and identified 4 distinct lithologic units based on variability in dry bulk density, organic matter, biogenic silica, carbon to nitrogen mass ratios (C/N), organic matter carbon isotopes (d13C), pollen, and elemental abundances via scanning X-ray fluorescence, with age control provided by 16 Accelerator Mass Spectrometry radiocarbon dates and 210Pb dating. In addition, we analyzed a transect of cores from 7.1 m, 10.75 m, 15.91 m, and 38.05 m water depths to identify lake level fluctuations and to characterize sediment compositional changes as a function of water depth. Organic matter content and magnetic susceptibility values in surface sediments from all transect cores show a strong correlation with water depth. Interpretation of four lithologic units with well-dated contacts produced a record of water-depth variations that is consistent with independent climate records from eastern Beringia. Basal coarse-grained sediments (quartz pebble diamicton) were deposited prior to 30,700 calendar years before present (yr BP), possibly from fluvial reworking or deflation during a period of severe aridity. Unit 1 sediments were deposited between 30,700 and 15,700 yr BP and are characterized by a low organic matter content, a high magnetic susceptibility, and low biogenic silica concentrations resulting from very low lake levels, low terrestrial and in-lake productivity and a high flux of clastic sediment. An abrupt increase in organic matter and biogenic silica concentration marks the transition into Unit 2 sediments, which were deposited between 15,700 and 9,400 yr BP when lake levels were higher and variable (relative to Unit 1). The transition to full interglacial conditions at 9,400 yr BP marks the beginning of Unit 3. Here an abrupt increase in the sedimentation rate, organic matter and biogenic silica concentration occurs (along with a corresponding decrease to low magnetic susceptibility). These high values persist until 8,700 yr BP, signifying a rapid rise to higher lake levels (in comparison to Units 1 and 2). Unit 4 sediments were deposited between 8,700 yr BP to 2010 AD and generally contain high concentrations of organic matter and biogenic silica with low magnetic susceptibility, suggesting that lake levels were relatively high and stable during the middle to late Holocene.

◆ **Fresco, N. 2012.** Chugach climate change scenarios project. Draft report. Scenarios Network for Alaska & Arctic Planning, University of Alaska, Fairbanks, Alaska. 25 pp.

Author introduction. Alaska is undergoing rapid changes. Substantial warming has occurred at high northern latitudes over the last half-century. Most climate models predict that high latitudes will experience a much larger rise in temperature than the rest of the globe over the coming century. At the same time, the state is undergoing rapid changes in human population and demands on natural resources. These changes mean that maintaining the status quo in operations and management of resources and growth may result in increased costs, risk, and resource damage. Future planning that accounts for these changes can avoid or reduce these potential liabilities.

For this project, the Scenarios Network for Alaska and Arctic Planning (SNAP: www/snap.uaf.edu), a program within the University of Alaska, provided objective scenarios based on climate projections and associated models of future landscape conditions. SNAP is a collaborative network that includes the University of Alaska, state, federal, and local agencies, NGO’s, and industry partners. The SNAP network provides timely access to scenarios of future conditions in Alaska and other Arctic regions for more effective planning by communities, industry, and land managers. The network meets stakeholders’ requests for specific information by applying new or existing research results, integrating and analyzing data, and communicating information and assumptions to stakeholders. SNAP’s goal is to assist in informed decision-making.

The projections used in this project were for a range of modeled data, including a baseline time period (1971-2000), the current decade (10’s), and future decades (20’s, 40’s, and 60’s). These data provided measurements of change as they are likely to manifest themselves in and around the Chugach National Forest. SNAP provided data on the effects of climate change on the following environmental factors: mean and extreme July and January temperature; mean and extreme July and January precipitation; timing of thaw and freeze; length of unfrozen season; and estimated snowline. In addition, SNAP provided information from the published literature regarding other potential climate-linked changes, including those associated with the Pacific Decadal Oscillation (PDO), ocean acidification, and storm frequency and intensity.

◆ **Gauthier, S., P. Bernier, P.J. Burton, J. Edwards, K. Isaac, N. Isabel, K. Jayen, H. Le Goff, E.A. Nelson. 2014.** Climate change vulnerability and adaptation in the managed Canadian boreal forest. Environmental Reviews, 10.1139/er-2013-0064.

Author abstract. Climate change is affecting Canada's boreal zone, which includes most of the country's managed forests. The impacts of climate change in this zone are expected to be pervasive and will require adaptation of Canada's forest management system. This paper reviews potential climate change adaptation actions and strategies for the forest management system, considering current and projected climate change impacts and their related vulnerabilities. These impacts and vulnerabilities include regional increases in disturbance rates, regional changes in forest productivity, increased variability in timber supply, decreased socioeconomic resilience, and increased severity of safety and health issues for forest communities. Potential climate change adaptation actions of the forest management system are categorized as those that reduce nonclimatic stressors, those that reduce sensitivity to climate change, or those that maintain or enhance adaptive capacity in the biophysical and human subsystems of the forest management system. Efficient adaptation of the forest management system will revolve around the inclusion of risk management in planning processes, the selection of robust, diversified, and no-regret adaptation actions, and the adoption of an adaptive management framework. Monitoring is highlighted as a no-regret action that is central to the implementation of adaptive forest management.

◆ **Gundale M.J., P. Kardol, M-C. Nilsson, U. Nilsson, R.W. Lucas, D.A. Wardle. 2014.** Interactions with soil biota shift from negative to positive when a tree species is moved outside its native range. New Phytologist; DOI: 10.1111/nph.12699

Author abstract: Studies evaluating plant–soil biota interactions in both native and introduced plant ranges are rare, and thus far have lacked robust experimental designs to account for several potential confounding factors.

- Here, we investigated the effects of soil biota on growth of *Pinus contorta*, which has been introduced from Canada to Sweden. Using Swedish and Canadian soils, we conducted two glasshouse experiments. The first experiment utilized unsterilized soil from each country, with a full-factorial cross of soil origin, tree provenance, and fertilizer addition. The second experiment utilized gamma-irradiated sterile soil from each country, with a full-factorial cross of soil origin, soil biota inoculation treatments, tree provenance, and fertilizer addition.
- The first experiment showed higher seedling growth on Swedish soil relative to Canadian soil. The second experiment showed this effect was due to differences in soil biotic communities between the two countries, and occurred independently of all other experimental factors.
- Our results provide strong evidence that plant interactions with soil biota can shift from negative to positive following introduction to a new region, and are relevant for understanding the success of some exotic forest plantations, and invasive and range-expanding native species.

◆ **Hamrick, J. L. 2004**. Response of forest trees to global environmental changes. Forest Ecology and Management **197**:323-335.

Author abstract: Characteristics of tree species may uniquely situate them to withstand environmental changes. Paleoecological evidence indicates that the geographic ranges of tree species have expanded and contracted several times since the last glacial epoch in response to directional environmental changes. For most tree species, these range fluctuations have been accomplished without any apparent loss of genetic diversity. A possible explanation that distinguishes most trees from many herbaceous plants is that much of the genetic variation within tree species is found within rather than among their populations. Thus, the extinction of a relatively large proportion of a tree species' populations would result in relatively little overall loss of genetic diversity. Furthermore, phylogeographic studies indicate that for some tree species, habitat heterogeneity (elevation, slope aspect, moisture, etc.) in glacial refugia may have preserved adaptive genetic variation that, when recombined and exposed to selection in newly colonized habitats, gave rise to the local adaptation currently seen.

The maintenance of genetic diversity in the face of extensive habitat fragmentation is also a concern. Many forest trees, however, may be buffered from the adverse effects of habitat fragmentation. First, the longevity of individual trees may retard population extinction and allow individuals and populations to survive until habitat recovery occurs. Second, considerable evidence is available that both animal and wind-pollinated tree species in fragments experience levels of pollen flow that are sufficient to counteract the effects of genetic drift. The combination of individual longevity, high intra-population genetic diversity and the potential for high rates of pollen flow should make tree species especially resistant to extinction and the loss of genetic diversity during changing environmental conditions.

◆ **Hogg, E.H. and R.W. Wein. 2005.** Impacts of drought on forest growth and regeneration following fire in southwestern Yukon, Canada. CJFR. 35(9): 2141-2150, 10.1139/x05-120**.**

Author abstract. The valleys of southwestern Yukon have a continental climate with average annual precipitation of <300 mm. In 1958, fires burned large areas of mature mixed wood forests dominated by white spruce (*Picea glauca* (Moench) Voss) in the valleys near Whitehorse. Since then, the burned areas have shown poor regeneration of spruce, but have been colonized by scattered clones of trembling aspen (*Populus tremuloides* Michx.) interspersed by grassland. The objective of the study was to examine the influence of climatic variation on forest growth and regeneration in the 1958 burn and the adjacent unburned forests. Tree-ring analysis was conducted on 50 aspen and 54 white spruce in 12 mature stands where these species were codominant, and on 147 regenerating aspen in the 1958 Takhini burn. The mature stands were uneven-aged and the patterns of growth variation for the aspen and spruce between 1944 and 2000 were similar. Growth of both species was most strongly related to variation in precipitation. The regenerating aspen had a wide age-class distribution (1959–2000) and their growth was also positively related to precipitation. The results indicate that these forests have been slow to regenerate after fire, and are vulnerable if the climate becomes drier under future global change.

◆ **Johnston, M., S. Webber, G.A. O'Neill, T. Williamson, and K. Hirsch. 2009.** Climate change impacts and adaptation strategies for the forest sector in Canada. In 2nd Climate Change Technology Conference, 12-15 May, 2009. Hamilton, ON. Engineering Institute of Canada.

Author abstract: Impacts on forests will vary regionally across Canada, with continental interior locations likely to experience greater extremes in temperature and precipitation. At the species level there will be short-term physiological responses to climate variability and long-term genetic responses to future climate change. Trees that are adapted to the climate at the time of establishment may be considerably maladapted to the climate at harvest time, displaying reduced productivity and increased frequency of pest attack. Although our ability to pro-actively mitigate possible short-term impacts to current climate change is limited, we have the opportunity to assist species and populations with migration to climatically-suitable habitats. This is a management activity called "assisted migration", and represents an important forest management activity to mitigate the negative consequences of climate change. Other possible management interventions to assist the adaptation of tree species include; improved tree breeding, altered silviculture activities, shorter rotation periods, use of exotics and fast-growing species. [PDF 373 kb]

◆ **Johnstone, J.F., E.J.B. McIntire, E.J. Pedersen, G. King, and M.J.F. Pisaric. 2010c.** A sensitive slope: estimating landscape patterns of forest resilience in a changing climate. Ecosphere 1:art14. http://dx.doi.org/10.1890/ES10-00102.1

Author abstract. Changes in Earth's environment are expected to stimulate changes in the composition and structure of ecosystems, but it is still unclear how the dynamics of these responses will play out over time. In long-lived forest systems, communities of established individuals may be resistant to respond to directional climate change, but may be highly sensitive to climate effects during the early life stages that follow disturbance. This study combined analyses of pre-fire and post-fire tree composition, environmental data, and tree ring analyses to examine landscape patterns of forest recovery after fire in the south-central Yukon, Canada, a climatically dry region of boreal forest where there is evidence of increasing drought stress. Pre-fire stand composition and age structures indicated that successional trajectories dominated by white spruce (*Picea glauca*) with little aspen (*Populus tremuloides*) comprised most of the study area during the last fire cycle. Although spruce seedling recruitment after the fire was highest at sites near unburned seed sources and where surface organic layers were shallow, spruce seedling densities were often insufficient to regenerate the pre-fire spruce forests. In particular, sites in the warmer topographic locations of the valley lowland and south-facing slopes typically had few spruce seedlings and instead were dominated by aspen. The opposite pattern was observed on north-facing slopes. Age reconstructions of pre-and post-fire stands indicate that future canopy composition is driven by initial post-fire recruitment and thus observed landscape differences in seedling recruitment are likely to be maintained through the next 100–200 years of succession. Observed results support the hypothesis that sites experiencing greater environmental stress show the lowest resilience to disturbance, or greatest compositional changes. Analyses of tree-ring responses to climate variables across the same landscape indicate that patterns of tree growth prior to a disturbance may be a useful predictor of landscape variations in forest resilience, allowing managers to better anticipate where future changes in forest composition are likely to occur.

◆ **Juday, G.P., V. Barber, E. Berg and D. Valentine. 1999**. Recent dynamics of white spruce treeline forests across Alaska in relation to climate. Pages 165-187 in S. Kankaanpaa, T. Tasanen and M.-L. Sutinen, editors. Sustainable development in northern timberline forests. Proceedings of the Timberline Workshop. The Finnish Forest Research Institute, Ministry of the Environment, Finland.

Author summary. (1) Treelines in Alaska show a strong response to the climate warming since the mid-19th century end of the Little Ice Age. The population structure of treeline white spruce in the central Alaska Range and southcentral coastal mountain regions is consistent with steady upslope recruitment of spruce in a warming climate since the mid 1800s. White spruce established since the Little Ice Age at the northwestern Alaska tree limit may be growing faster than spruce established earlier in colder conditions.

(2) White spruce at latitudinal and upper elevation treeline in Alaska are generally vigorous and have been able to reproduce steadily or at least at periodic intervals since the beginning of the 20th century or earlier. Particular years with favorable weather for triggering white spruce cone crops include 1912, 1915, 1926, and especially 1940. Many of the well established treeline trees of today at central Alaska treelines may date from the 1940 or 1941 seed crop.

(3) A low elevation treeline in contact with grassland occurs in the dry central interior portion of Alaska. If recent warming and drying trends there persist or intensify, direct and indirect effects of moisture stress could result in white spruce retreat and expansion of grassland or aspen parkland.

(4) Strong climate warming has occurred widely across Alaska, especially since 1976. Some locations, such as the central Brooks Range have experienced increased summer temperatures and increased summer precipitation. An index of moisture stress composed of summer temperature and annual precipitation at Fairbanks records sustained, high levels of moisture stress since 1976.

(5) Only a small proportion of treeline spruce in the in the mountains of southcentral Alaska are sensitive to summer temperature. The actual elevational limit for growth of spruce in the mountains of southcentral Alaska may be substantially higher than the current elevation of established trees.

◆ **Juday, G.P., V. Barber, S. Rupp, J. Zasada, M.W. Wilmking. 2003.** A 200-year perspective of climate variability and the response of white spruce in Interior Alaska. In: Greenland, D., D. Goodin, and R. Smith (eds.). Climate Variability and Ecosystem Response at Long-Term Ecological Research (LTER) Sites. Oxford University Press. Chapter 12 Pp. 226-250.

Compiler summary. This publication documents ecological responses in white spruce related to climate variability at Bonanza Creek. The long time series allows the identification of repeated outcomes, including changes in climate, tree growth, seed crop timing and abundance, and stand age cohort parameters.

This study analyzes the impact of El Niño years on seed crops and burned acreage. Strong and moderate El Niños generally produce positive temperature anomalies in Interior Alaska but generally below normal precipitation, particularly in the winter (Hess et al. 2001, Ropelewski and Halpert 1986).

Some treeline populations of white spruce in Alaska no longer respond to increased warmth (Jacoby et al. 1999). Juday et al. 1999 demonstrated that Alaska treelines respond in different ways to recent climate warming, depending on the location and environmental setting of the treeline. Under some scenarios, changing temperature sensitivity could become a widespread phenomenon, and treeline climate reconstructions should be viewed with caution.

The key cue of environmental variability for white spruce is a critical period of warm and dry early summer weather in successive years, which generates strong stress (Owens and Mulder 1977). These same dry weather conditions represent fire weather (Johnson et al. 1992). It appears that the described reproductive timing of white spruce maximizes the odds that seeds will be released into a landscape in which fires have occurred recently, and the thick organic mat of the forest floor is reduced or removed. A disproportionate share of the living young white spruce trees less than 50 years in Interior Alaska are the result of reproduction in 1958, 1970, 1987, 1998. On average only about 14 major reproductive events occur during the life of a white spruce stand.

◆ **Juday, G.P., V. Barber, E. Vaganov, S. Rupp, S. Sparrow, J. Yarie, H. Linderholm, E. Berg, R. D'Arrigo, P. Duffy, O. Eggertsson, V.V. Furyaev, E.H. Hogg, S. Huttunen, G. Jacoby, V.Ya. Kaplunov, S. Kellomaki, A.V. Kirdyanov, C.E. Lewis, S. Linder, M.M. Naurzbaev, F.I. Pleshikov, Yu.V. Savva, O.V. Sidorova, V.D. Stakanov, N.M. Tchebakova, E.N. Valendik, E.F. Vedrova, and M. Wilmking. 2005.** Forests, Land Management, Agriculture. In Arctic Climate Impact Assessment, Arctic Council, Cambridge University Press, pages 781-862.

Compiler summary. This publication synthesizes information on forest, land management, and agriculture interactions with climate change and carbon storage across the boreal region in North America, Scandinavia, and Russia.

Tree growth and warm- season temperature have irregularly decreased in northernmost Eurasia and North America from the end of the postglacial thermal maximum through the end of the 20th century. Long-term tree-ring chronologies from Russia, Scandinavia, and North America record the widespread occurrence of a Medieval Warm Period about 1000 years BP, a colder Little Ice Age ending about 150 years ago, and more recent warming. Recent decades were the warmest in a millennium or more at some locations. Temperature and tree growth records generally change at the same time and in the same direction across much of the Arctic and subarctic.

The record of past forest advances suggests that there is a solid basis for projecting similar treeline change under climate change producing similar temperature increases. It also suggests that the components of ecosystems present today have the capacity to respond and adjust to such climate fluctuations. In northeast Canada, recent milder winters have permitted stems that were restricted to snow height by cold and snow abrasion to emerge in upright form, and future climate projected by the ACIA-designated models would permit viable seed production, which is likely to result in infilling of the patchy forest–tundra border and possibly begin seed rain onto the tundra. In the Polar Ural Mountains, larch reproduction is associated with warm weather, and newly established trees have measurably expanded forest cover during the 20th century.

Across the boreal forest, warmer temperatures in the last several decades have affected tree growth, depending on species, site type, and region. Temperature-induced drought stress has been identified as the cause of reduced growth in some areas, but other declines are not currently explained. Reduced growth in years with high temperatures is common in treeline white spruce in western North America, suggesting reduced potential for treeline movement under a warming climate. Tree growth is increasing in some locations, generally where moisture and nutrients are not limiting, such as in the boreal regions of Europe and eastern North America. The five ACIA-designated models project climates that empirical relationships suggest are very unlikely to allow the growth of commercially valuable white spruce types and widespread black spruce types in major parts of Alaska and probably western boreal Canada. The upper range of the model projections represents climates that may cross ecological thresholds, and it is possible that novel ecosystems could result, as during major periods of global climate change in the past.

Large-scale forest fires and outbreaks of tree-killing insects are characteristic of the boreal forest, are triggered by warm weather. Climate change effects on disturbance include a greater frequency of fire or insect outbreaks, more extensive areas of tree mortality, and more intense disturbance resulting in higher average levels of tree death or severity of burning.

Different crop species and even varieties of the same species can exhibit substantial variability in sensitivity to ultraviolet-B (UV-B) radiation. In susceptible plants, UV-B radiation causes gross disruption of photosynthesis, and may inhibit plant cell division. Damage by UV-B radiation is likely to accumulate over the years in trees. Evergreens receive a uniquely high UV radiation dose in the late winter, early spring, and at the beginning of the growing season because they retain leaves during this period when exposure is amplified by reflectance from snow cover. Exposure to enhanced levels of UV-B radiation induces changes in the anatomy of needles on mature Scots pine similar to characteristics that enhance drought resistance. UV-B radiation plays an important role in the formation of secondary chemicals in birch trees at higher latitudes. Secondary plant chemicals released by birch exposed to increased UV-B radiation levels might stimulate its herbivore resistance.

◆ **Juday, G.P., T. Grant III, and D.L. Spencer. 2012.** Boreal Alaska aspen growth rate collapse and mortality from high temperatures, drought, and insect attack. Presentation to: Ecol. Soc. of America annual meeting. Aug. 10, 2012.

Compiler summary. The authors measured tree disks from 117 aspens trees in seven stands across central and eastern Interior Alaska. Tree disk data were compared to mean monthly temperature and monthly total precipitation data from Fairbanks from 1912 through 2011. The authors reported that warm summer temperatures were a negative predictor of growth, and precipitation in specific months was a positive predictor. From the mid-1970s through the 1990s, strongly unfavorable climate index values were associated with a major growth reduction. A sustained leaf miner outbreak further reduced growth.

◆ **Juday, G.P., R.A. Ott, D.W. Valentine and V.A. Barber. 1998.** Forests, climate stress, insects, and fire. Pp. 23-49 in G. Weller, and P. Anderson, editors. Implications of global change in Alaska and the Bering Sea region. Center for Global Change and Arctic System Research, University of Alaska Fairbanks, Fairbanks, Alaska, USA.

Compiler summary. The authors identify numerous potential changes in the Alaska boreal forest under projected climate change scenarios and summarize them according to confidence and degree of impact. Potential changes affecting reforestation include:

• A period of widespread insect-caused mortality and severe/extensive forest fires across interior and southcentral Alaska would occur.

• Earlier onset of plant growth in the spring and prolonged growing seasons in the fall ("shoulder seasons") will deepen the regional moisture deficit at low elevation forest sites. The Tanana and Yukon Valleys will become more like the aspen parkland typical of Edmonton, Alberta.
• Aspen, birch, and tamarack forests would experience more frequent and widespread defoliation by insects, including the large aspen tortrix (*Choristoneura conflictana*), spear-marked black moth (*Rheumaptera hastata*), birch leaf roller (*Epinotia solandriana*), larch sawfly (*Pristiphora erichsonii*), and bronze birch borer (*Agrilus anxius*).
• Forest regeneration failure and drought-induced tree mortality on low-elevation south slopes would occur, followed by grassland expansion.
• Forest expansion into tundra would occur westward on the Seward Peninsula.
• Forest expansion into tundra would occur upward in elevation in a relatively limited zone in the Brooks Range, Alaska Range, Chugach Mountains, and Yukon-Tanana Uplands.
• Following the fires, there would be a shortage of white spruce seed for regeneration because of unfavorable climate, population reduction, and tree isolation. Newly regenerating forests will be composed of greater proportions of aspen, birch, grassland, and shrubland than the current landscape.
• Fire frequency would increase in general, and the average fire return interval in any given forest landscape will be decreased. More frequent fires will help maintain grassland against forest recolonization.
• White spruce cone crops will be produced less frequently because of sustained periods of warm and dry weather.

The authors also identify research needs and recommend mitigation measures including
• Design and fund a forest regeneration program to enhance or supplement forest responses to global warming effects. Prepare to plant increased amounts of local seed sources of white spruce and to supplement it on managed or salvage logged sites. Launch a tree improvement program to find the best adapted genotypes of white spruce in a changing environment.
• Reduce the number of trees in overstocked managed stands to reflect lower actual carrying capacity in new higher-stress environments. Manage more carefully to avoid creating dense stagnant stands that could serve as local initiation points for widespread tree-damaging insect outbreaks.
• Promote a diverse mix of tree and other plant species.

◆ **Juday, G.P., R.A. Ott, D.W. Valentine, and V.A. Barber. 1997.** Assessment of actual and potential global warming effects on forests of Alaska. Pages 121-126 in New England Regional Climate Change Impacts Workshop. Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, Durham, New Hampshire, USA.

Compiler summary. This paper summarizes climate warming and drying trends in coastal and boreal forests in Alaska over the last 20 years, and describes the current and potential impacts of these changes.
Key points related to boreal forests include:

- Warm early spring and summer weather is apparently a necessary trigger factor in the production of the infrequent excellent white spruce cone and seed crops (Alden 1985, Zasada et al 1992). Until recently the occurrence of a high number of days with warm temperatures in the early summer would be followed predictably the following year by a white spruce cone crop, unless a crop was already being produced in the trigger year. In the last decade or more, greater numbers of warm days than ever have occurred but crops are not being formed.

- Annual precipitation and summer precipitation have decreased during the entire period of record in Fairbanks (1906-96). Summer precipitation has decreased at rate of 17% per century at Fairbanks.
- White spruce growth is positively related to precipitation and negatively related to temperature. White spruce trees on productive sites near Fairbanks have become moisture stressed due to longer growing seasons. Treeline trees that were previously limited only by warmth, are now limited by moisture stress (Jacoby and D'Arrigo, 1995).
- Continued warming and drying would interfere with reproduction of white spruce. Warming of the interior Alaska climate without a sufficient increase in precipitation that was effective in supplying water to the forest in the driest part of the year (mid and late summer) would probably transform large areas of productive lowland boreal
- Future climate change could increase damage from defoliators and tree-boring insects that have previously had outbreaks in Alaska, and from insect species that have not been produced landscape-level effects on Alaska's forests in the recent past.
- The likelihood of a transition period of large fires in the Alaskan boreal forest is substantial, because overall area burned is well correlated with the average summer temperature, and large areas of standing dead forest provide fuel that would be difficult to keep from burning once ignited. The fire potential following a transition period of large fires is less certain. The new landscape probably would support a fewer conifer stands and more hardwood stands that would be relatively fire-resistant.
- If reproduction of desired species is not certain in the future, forest management plans may need to be adjusted today. Artificial tree regeneration can help mitigate this problem, but costs and other land management objectives must be addressed.

◆ **Keller S.R., R.Y. Soolanayakanahally, R.D. Guy, S.N. Silim, M.S. Olson, and P.Tiffin. 2011.** Climate-driven local adaptation of ecophysiology and phenology in balsam poplar, Populus balsamifera L. (Salicaceae). American Journal of Botany 98(1): 99-108.

Author abstract: During past episodes of climate change, many plant species experienced large-scale range expansions. Expanding populations likely encountered strong selection as they colonized new environments. In this study we examine the extent to which populations of the widespread forest tree Populus balsamifera L. have become locally adapted as the species expanded into its current range since the last glaciation.

We tested for adaptive variation in 13 ecophysiology and phenology traits on clonally propagated genotypes originating from a range-wide sample of 20 subpopulations. The hypothesis of local adaption was tested by comparing among-population variation at ecologically important traits (Q(ST)) to expected variation based on demographic history (F(ST)) estimated from a large set of nuclear single nucleotide polymorphism loci.

Evidence for divergence in excess of neutral expectations was present for eight of 13 traits. Bud phenology, petiole length, and leaf nitrogen showed the greatest divergence (all Q(ST) > 0.6), whereas traits related to leaf water usage showed the least (all Q(ST) ≤ 0.30) and were not different from neutrality. Strong correlations were present between traits, geography, and climate, and they revealed a general pattern of northern subpopulations adapted to shorter, drier growing seasons compared with populations in the center or eastern regions of the range.

Our study demonstrates pronounced adaptive variation in ecophysiology and phenology among balsam poplar populations. These results suggest that as this widespread forest tree species expanded its range since the end of the last glacial maximum, it evolved rapidly in response to geographically variable selection.

◆ **Kranabetter, J.M., M.U. Stoehr, and G.A. O'Neill. 2012.** Divergence in ectomycorrhizal communities with foreign Douglas-fir populations and implications for assisted migration. Ecological Applications 22(2):550-560

Author abstract. Assisted migration of forest trees has been widely proposed as a climate change adaptation strategy, but moving tree populations to match anticipated future climates may disrupt the geographically based, coevolved association suggested to exist between host trees and ectomycorrhizal fungal (EMF) communities. We explored this issue by examining the consistency of EMF communities among populations of 40 year-old Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) trees in a common-garden field trial using four provenances from contrasting coastal climates in southwestern British Columbia. Considerable variation in EMF community composition within test sites was found, ranging from 0.38 to 0.65 in the mean similarity index, and the divergence in EMF communities from local populations increased with site productivity. Clinal patterns in colonization success were detected for generalist and specialist EMF species on only the two productive test sites. Host population effects were limited to EMF species abundance rather than species loss, as richness per site averaged 15.0 among provenances and did not differ by transfer extent (up to 450 km), while Shannon's diversity index declined slightly. Large differences in colonization rates of specialist fungi, such as *Tomentella stuposa* and *Clavulina cristata*, raise the possibility that EMF communities maladapted to soil conditions contributed to the inferior growth of some host populations on productive sites. The results of the study suggest locally based specificity in host–fungal communities is likely a contributing factor in the outcome of provenance trials, and should be a consideration in analyzing seed-transfer effects and developing strategies for assisted migration. [Link]

◆ **Leech, S.M., P.L. Almuedo, and G. O'Neill. 2011.** Assisted Migration: Adapting forest management to a changing climate. BC Journal of Ecosystems and Management 12(3):18-34.

Author abstract: Forestry practitioners are increasingly interested in how to adapt practices to accommodate predicted changes in climate. One forest management option involves helping tree species and seed sources (populations) track the movement of their climates through "assisted migration": the purposeful movement of species to facilitate or mimic natural population or range expansion. In this paper, we discuss assisted migration as a climate change adaptation strategy within forest management. Substantial evidence suggests that most tree species will not be able to adapt through natural selection or migrate naturally at rates sufficient to keep pace with climate change, leaving forests susceptible to forest health risks and reduced productivity. We argue that assisted migration is a prudent, proactive, inexpensive strategy that exploits finely tuned plant-climate adaptations wrought through millennia of natural selection to help maintain forest resilience, health and productivity in a changing climate. Seed migration distances being considered in operational forestry in British Columbia are much shorter than migration distances being contemplated in many conservation biology efforts and are informed by decades of field provenance testing. Further, only migrations between similar biogeoclimatic units are under discussion. These factors reduce considerably the risk of ecological disturbance associated with assisted migration. To facilitate the discussion of assisted migration, we present three forms of assisted migration, and discuss how assisted migration is being considered internationally, nationally, and provincially. Finally, we summarize policy and research needs and provide links to other resources for further reading. [PDF 303 kb]

◆ **Lev, D.J. 1987.** Balsam poplar (Populus balsamifera) in Alaska : ecology and growth response to climate. Unpubl. M.S. Thesis, University of Washington, Seattle. 70 p.

Author introduction (excerpt). Balsam poplar *(Populus balsamifera)* grows farther north than any other tree species in Alaska and in some areas also defines the alpine limit of trees {Viereck and Little, 1972; Edwards and Dunwiddie, 1985). The species survives flooding on low elevation river terraces and can be found in the driest parts of the state. Balsam poplar is the first t:ree to colonize newly exposed river gravel and was the f:!rst tree species to gain importance in northern Alaska after retreat of the late-Wisconsin glaciers. Yet little research has .been done on this remarkable species.

This study examines balsam poplar's ecology and growth response to climate at three different locations in Alaska: the Brooks Range, Alaska Range and Interior Lowland. The species' response to climate is used to help interpret Paleoecological conditions and to infer phenology at these sites. Since poplar stands of Alaska's interior floodplains have been described (Viereck, 1970), the site description and vegetation analysis parts of this study focus on the tree limit locations in the Brooks Range and Alaska Range.

Stands of balsam poplar at the alpine limits of trees are particularly interesting since the species usually occurs as a colonizer of floodplain sites in the boreal forest (Zasada and Phipps, 1983). The species does possess several traits that explain its appearance at tree limit. With its ability to reproduce from root sprouts, an individual balsam poplar can maintain itself through long periods of hostile climate conditions (Barnes, 1966). Isolated, catastrophic events that destroy an entire stand of individuals may stimulate root sprouting *to* replace poplars. Since poplar is deciduous, it is not subject to severe winter desiccation described for treeline conifers, where warm spring temperatures encourage transpiration through leaves while water uptake by roots is prevented in still frozen ground (Tranquiliini, 1963, 1976).

Isolated stands of poplar in the-Brooks Range have also sparked the interest of paleo-ecologists who search for modern analogs to past vegetation. Palynological studies in northern Alaska and northwestern Canada have shown a peak in poplar pollen of up to 40% during the period of 11,000 to 9,000years B.P. (Cwyner, 1982; Ritchie, 1984; Ager and Brubaker;1985) Ritchie *eta/.* (1983) interpret the *Populus* peak as an indication of an early Holocene warm period. According to the Milankovitch theory of climate change, at 9,000 years B.P. the earth was closest to the sun during northern hemisphere summer, creating warm arctic growing seasons (Ritchie *et al.*, 1983).

Dendroclimatic studies generally relate annual tree growth to monthly or annual climatic data summaries but short arctic growing seasons may call for finer temporal resolution. In this study, climatic data from Alaskan weather stations have been summarized by five-day periods. Results of the analyses using monthly and five-day climatic summaries are compared. The climate-growth analysis is also used to infer and compare phenology at the three different locations. The results of this study suggest that phenological inference from tree-rings may be a useful tool for evaluating populations in remote areas where continual observation is not possible.

◆ **Lloyd, A.H., P.A. Duffy, and D.H. Mann. 2013**. Nonlinear responses of white spruce growth to climate variability in interior Alaska. Can. J. For. Res., 2013, 43(999): 331-343, 10.1139/cjfr-2012-0372

Author abstract. Ongoing warming at high latitudes is expected to lead to large changes in the structure and function of boreal forests. Our objective in this research is to determine the climatic controls over the growth of white spruce (*Picea glauca* (Moench) Voss) at the warmest driest margins of its range in interior Alaska. We then use those relationships to determine the climate variables most likely to limit future growth. We collected tree cores from white spruce trees growing on steep, south-facing river bluffs at five sites in interior Alaska, and analyzed the relationship between ring widths and climate using boosted regression trees. Precipitation and temperature of the previous growing season are important controls over growth at most sites: trees grow best in the coolest, wettest years. We identify clear thresholds in growth response to a number of variables, including both temperature and precipitation variables. General circulation model (GCM) projections of future climate in this region suggest that optimum climatic conditions for white spruce growth will become increasingly rare in the future. This is likely to cause short-term declines in productivity and, over the longer term, probably lead to a contraction of white spruce to the cooler, moister parts of its range in Alaska.

◆ **Lloyd, A.H., T.S. Rupp, C.L. Fastie, and A.M. Starfield. 2002.** Patterns and dynamics of treeline advance on the Seward Peninsula, Alaska. J. Geophys. Res., 107, *8161, doi:*10.1029/2001JD000852. 108(D2), 2003.

Author abstract. Boreal tree species are expected to invade tundra ecosystems as climate warms. Because forested ecosystems differ from tundra ecosystems in a number of climatically relevant characteristics, this advance of the altitudinal and latitudinal tree limit may ultimately feedback on regional climate. We used tree rings to reconstruct the response of the treeline ecotone on the Seward Peninsula in northwestern Alaska to 20th century warming. We further explored the sensitivity of the treeline ecotone to climate change using the spatially explicit, frame-based model ALFRESCO. Our reconstructions of forest response to past warming indicate that in upland tundra spruce have successfully established progressively farther from the forest limit since the 1880s. Shrub tundra has thus been converted to low-density forest–tundra within a band extending approximately 10 km from the forest limit. In lowland sites, where soil thermal and hydrologic properties are the primary constraint on tree distribution, trees began establishing in tundra after 1920, and establishment was restricted to areas that had experienced thermokarst activity in the past. Modeling experiments suggested that changes in disturbance regime and spruce growth response to climate may introduce strongly nonlinear responses to climate change at treeline. Field data and model experiments thus both indicate that large and nearly instantaneous responses to warming are likely at the treeline ecotone but that sensitivity to warming is likely to vary substantially over space and time.

◆ **Man, R. S.J. Colombo, P. Lu, and Q-L. Dang. 2014.** Trembling aspen, balsam poplar, and white birch respond differently to experimental warming in winter months. Canadian Journal of Forest Research, 10.1139/cjfr-2014-0302

Author abstract. Climatic warming may increase temperature variability, especially in winter months, leading to increased risk of early loss of cold hardiness during winter and therefore freezing damage. In this study, the responses of seedlings of three boreal broadleaf species, trembling aspen, balsam poplar, and white birch, to experimental warming in winter months from November to March were examined in terms of changes in cold hardiness (measured based on electrolyte leakage), budbreak, and survival. Seedling responses were greater in winter (January) and spring (March) than in the fall (November) and were greater in trembling aspen and balsam poplar than in white birch. Warming for 5- or 10-days at 16oC day/-2oC night at a 10 hour photoperiod in winter and spring generally reduced cold hardiness, which, due to freezing temperatures in the post-warming ambient environment, led to increased mortality and stem dieback and longer time to budbreak. There was some increase in cold hardiness after 10 days of returning to outdoor environment following warming in spring, when ambient temperatures were less damaging than in winter. The resistance of white birch to warming, likely due to its greater thermal requirement for budbreak and slower natural dehardening, suggests that white birch is better suited to withstand increasing winter temperature variability that might occur under future climate conditions. Information on thermal sum for budbreak, response to winter warming, and natural dehardening can improve budbreak prediction and phenological modeling for these boreal broadleaf species.

◆ **McGuire, A.D., R.R., Ruess, A. Lloyd, J. Yarie, J.S. Clein, and G.P. Juday. 2010.** Vulnerability of white spruce tree growth in interior Alaska in response to climate variability: dendrochronological, demographic, and experimental perspectives. Canadian Journal of Forest Research, 2010, 40(7): 1197-1209, 10.1139/X09-206

Author abstract. This paper integrates dendrochronological, demographic, and experimental perspectives to improve understanding of the response of white spruce (Picea glauca (Moench) Voss) tree growth to climatic variability in interior Alaska. The dendrochronological analyses indicate that climate warming has led to widespread declines in white spruce growth throughout interior Alaska that have become more prevalent during the 20th century. Similarly, demographic studies show that white spruce tree growth is substantially limited by soil moisture availability in both mid- and late-successional stands. Interannual variability in tree growth among stands within a landscape exhibits greater synchrony than does growth of trees that occupy different landscapes, which agrees with dendrochronological findings that the responses depend on landscape position and prevailing climate. In contrast, the results from 18 years of a summer moisture limitation experiment showed that growth in midsuccessional upland stands was unaffected by moisture limitation and that moisture limitation decreased white spruce growth in floodplain stands where it was expected that growth would be less vulnerable because of tree access to river water. Taken together, the evidence from the different perspectives analyzed in this study clearly indicates that white spruce tree growth in interior Alaska is vulnerable to the effects of warming on plant water balance.

◆ **Okano, K. 2012.** Growth Response of White Spruce [Picea glauca (Moench) Voss] in Denali National Park under Warming Climate. Poster URI:http://hdl.handle.net/11122/1559

Author abstract. In subarctic mountains such as Denali National Park and Preserve (DNP), vegetation shifts from alpine tundra to boreal forests caused by recent climate change are a potential threat to plant conservation and indirectly to animal habits and diversity, which could affect the experience of visitors who wish to see wildlife. The growth rate of Picea glauca (white spruce) could decrease by climate change due to drought stress, which might lead to species elimination. The shift of P. glauca towards a higher elevation would require its seedlings not only to adapt to new abiotic harsh conditions, but also to compete with other plant species that are already present.

◆ **O'Neill, G.A., M.R. Carlson, V. Berger, and A.D. Yanchuk. 2007**. Responding to climate change: assisting seedlot migration to maximize adaptation of future forest plantations. Ticktalk 8: 9-12.

Author abstract: Little is currently known regarding the adaptive responses of breeding populations of BC's commercially important tree species. To ensure that each reforestation site receives the Class A seedlots that are best adapted and most productive for its current and future climate, each breeding/ production population must be tested across a broad range of climatic and latitudinal environments. The Assisted Migration Adaptation Trial (AMAT) intends to test the 35 breeding/ production populations (i.e., Class A seed orchard seedlots for which seed is available, from BC and western States) across 48 test sites. Twelve field tests per year for each of four years will be established throughout BC and neighbouring states, beginning in spring 2009. Use of local control (wild stand) seedlots and a block plot layout will enable realized genetic gains to be estimated for each population. Productivity of each population will be described as a function of the climate and latitude of the test sites, enabling development of a deployment system that will maximize forest productivity while ensuring the widest deployability of every orchard seedlot. [PDF 510 kb]

◆ **O'Neill, G.A., N.K. Ukrainetz, M.R. Carlson, C.V. Cartwright, B.C. Jaquish, J.N. King, J. Krakowski, J.H. Russell, M.U. Stoehr, C-Y. Xie, and A.D. Yanchuk. 2008.** Assisted migration to address climate change in British Columbia: recommendations for interim seed transfer standards. B.C. Min. For. Range, Res. Br., Victoria, B.C. Tech. Rep. 048.

Author abstract: Columbia becoming increasingly maladapted to the climates in which they are planted. Consequently, planting seedlings adapted to future climates (assisted migration) is recognized as a key strategy to address climate change, as it will help maintain healthy, productive forests, and ensure capture of gains obtained from decades of selective breeding.

To examine opportunities to incorporate assisted migration into British Columbia's seed transfer system, the feasibility of increasing the upper elevational transfer limit of British Columbia's Class A and Class B seed was assessed by calculating the climatic transfer distance associated with elevational transfers. A rationale was developed for quantifying an appropriate climatic distance and range to migrate seed, and was used to evaluate elevational transfer increases of 100 and 200 m.

Results indicate that of the 30 Class A Seed Planning Units (spus) examined, eight should retain their current upper elevation limits, one should have its upper elevation limit increased by 100 m, and the remainder should have their upper elevation limits increased by 200 m. Upper elevation transfer limits of Class B seed should be increased by 200 m for eight species, by 100 m for two species, and should remain unchanged for three species. Specific recommendations are provided in Tables 2 and 3.

Deployment of orchard seed in the lowest 200 m of the western white pine—Maritime and interior spruce—East Kootenay spus is discouraged, as is transfer of Class B seed of amabilis fir and western hemlock more than 200 m downward and western redcedar more than 300 m downward. [PDF 6286 kb]

◆ **Pedlar, J.H., D.W. McKenney, I. Aubin, T. Beardmore, J. Beaulieu, L. Iverson, G.A. O'Neill, R.S. Winder, and C. Ste-Marie. 2012.** Placing Forestry in the Assisted Migration Debate. Bioscience 62(9):835-842

Author abstract. Assisted migration (AM) is often presented as a strategy to save species that are imminently threatened by rapid climate change. This conception of AM, which has generated considerable controversy, typically proposes the movement of narrowly distributed, threatened species to suitable sites beyond their current range limits. However, existing North American forestry operations present an opportunity to practice AM on a larger scale, across millions of hectares, with a focus on moving populations of widely distributed, nonthreatened tree species within their current range limits. Despite these differences (and many others detailed herein), these two conceptions of AM have not been clearly distinguished in the literature, which has added confusion to recent dialogue and debate. Here, we aim to facilitate clearer communication on this topic by detailing this distinction and encouraging a more nuanced view of AM. [Link]

◆ **Pedlar, J., D. McKenney, J. Beaulieu, S. Colombo, J. McLachlan, and G. O'Neill. 2011.** The implementation of assisted migration in Canadian forests. For. Chron. 87(6):766-777

Author abstract. We outline the major steps involved in implementing assisted migration (AM) and assess, in a general way, the capacity to carry out each step in Canadian forests. Our findings highlight the fact that capacity to implement AM differs between forest species; in particular, the existence of established provenance trials, seed transfer guidelines, seed procurement systems, and plantation establishment protocols makes AM considerably more feasible for most commercial tree species than for most species of conservation concern. We report on several AM efforts involving commercial tree species that are already underway in Canada and identify a number of initiatives that could be undertaken to help build AM capacity. This paper is not intended as an endorsement of the AM approach; however, we feel there is considerable value in discussing implementation issues at this point in the AM debate. [Link]

◆ **Peterson, D.L., C.I. Millar, L.A. Joyce, M.J. Furniss, J.E. Halofsky, R.P. Neilson, and T.L. Morelli. 2011.** Responding to climate change in national forests: a guidebook for developing adaptation options. USDA Forest Service, Pacific Northwest Research Station, General Technical Report. PNW-GTR-855. Portland, Oregon. 109 p.

Author abstract. This guidebook contains science-based principles, processes, and tools necessary to assist with developing adaptation options for national forest lands. The adaptation process is based on partnerships between local resource managers and scientists who work collaboratively to understand potential climate change effects, identify important resource issues, and develop management options that can capitalize on new opportunities and reduce deleterious effects. Because management objectives and sensitivity of resources to climate change differ among national forests, appropriate processes and tools for developing adaptation options may also differ. Regardless of specific processes and tools, the following steps are recommended: (1) become aware of basic climate change science and integrate that understanding with knowledge of local resource conditions and issues (review), (2) evaluate sensitivity of specific natural resources to climate change (rank), (3) develop and implement strategic and tactical options for adapting resources to climate change (resolve), and (4) monitor the effectiveness of adaptation options (observe) and adjust management as needed. Results of recent case studies on adaptation in national forests and national parks can facilitate integration of climate change in resource management and planning and make the adaptation process more efficient. Adaptation to climate change will be successful only if it can be fully implemented in established planning processes and other operational aspects of national forest management.

◆ **Price, D.T., R.I. Alfaro, K.J. Brown, M.D. Flannigan, R.A. Fleming, E.H. Hogg, M.P. Girardin, T. Lakusta, M. Johnston, D.W. McKenney, J.H. Pedlar, T. Stratton, R.N. Sturrock, I.D. Thompson,[c] J.A. Trofymow, L.A. Venier**. **2013.** Anticipating the consequences of climate change for Canada's boreal forest ecosystems. Environmental Reviews. 21(4): 322-365, 10.1139/er-2013-0042.

Author abstract. Canadian boreal woodlands and forests cover approximately 3.09×10^6 km^2, located within a larger boreal zone characterized by cool summers and long cold winters. Warming since the 1850s, increases in annual mean temperature of at least 2 °C between 2000 and 2050 are highly probable. Annual mean temperatures across the Canadian boreal zone could be 4–5 °C warmer than today's by 2100. All aspects of boreal forest ecosystem function are likely to be affected. Further, several potential "tipping elements" — where exposure to increasing changes in climate may trigger distinct shifts in ecosystem state — can be identified across the Canadian boreal zone. Approximately 40% of the forested area is underlain by permafrost, some of which is already degrading irreversibly, triggering a process of forest decline and re-establishment lasting several decades, while also releasing significant quantities of greenhouse gases that will amplify the future global warming trend. Warmer temperatures coupled with significant changes in the distribution and timing of annual precipitation are likely to cause serious tree-killing droughts in the west; east of the Great Lakes, however, where precipitation is generally nonlimiting, warming coupled with increasing atmospheric carbon dioxide may stimulate higher forest productivity. Large wildfires, which can cause serious economic losses, are expected to become more frequent, but increases in mean annual area burned will be relatively gradual. The most immediate threats could come from endemic forest insect pests that have the potential for population outbreaks in response to relatively small temperature increases. Quantifying the multiple effects of climate change will be challenging, particularly because there are great uncertainties attached to possible interactions among them, as well as with other land-use pressures. Considerable ingenuity will be needed from forest managers and scientists to address the formidable challenges posed by climate change to boreal

ecosystems and develop effective strategies to adapt sustainable forest management practices to the impending changes.

◆ **Robertson A.L. 2012.** Acclimation and migration potential of balsam poplar, Populus balsamifera L., in a changing climate. Unpublished Univ. of Alaska Fairbanks PhD thesis.

Author abstract. In the North American boreal forest, 21st century climate change is projected to result in longer growing seasons, increased forest productivity, and northward expansions or shifts in species ranges. These projected impacts are largely based on observations across natural temperature gradients, e.g., latitude or altitude, or correlations between current species' distributions and modern climate envelopes. These approaches, although valuable, do not consider biological capacities important in a species' ability to cope with novel environments through physiological or phenological acclimation. Within a single species, adaptation to local environments may cause some populations to respond differently to climate change than others. Acclimation (phenotypic plasticity) is often treated as a separate phenomenon from local adaptation, but the latter may determine the range of acclimation responses or thresholds. To more accurately predict how boreal tree species will respond to a directionally changing climate, it is necessary to experimentally examine the effects of warming on the growth and physiology of individual species and how those effects differ across a species' range. This research investigated how tree growth responses to increasing temperature are influenced by differences in adaptation and acclimation across the latitudinal range of the North American boreal forest tree, Populus balsamifera L. (balsam poplar). Warming experiments, both in the greenhouse and in the field, indicated that growth of balsam poplar trees from a broad latitudinal gradient responds positively to increased growing temperatures, with increases in height growth ranging from 27-69 % in response to 3-8 °C average warming. Genotypes from southern populations grew consistently taller in both field and greenhouse experiments. The field experiment enabled investigation into the effects of warming and source latitude on balsam poplar phenology; both experimentally warmed and southern individuals grew larger and exhibited longer growing seasons (more days of active growth). Lastly, I describe a theoretical/methodological framework for exploring the role of epigenetics in acclimation (plasticity) and adaptation to changing environments. The results from these experiments are integrated with information on adaptive gradients in balsam poplar to predict both the in situ responses of balsam poplar to increased temperatures, and the potential for northward range shifts in the species.

◆ **Roland, C.A., J.H. Schmidt, and J.F. Johnstone. 2013a.** Climate sensitivity of reproduction in a mast-seeding boreal conifer across its distributional range from lowland to treeline forests. Oecologia. Published online Nov. 10, 2013. The final publication is available at link.springer.com

Author abstract: Mast-seeding conifers such as *Picea glauca* exhibit synchronous production of large seed crops over wide areas, suggesting climate factors as possible triggers for episodic high seed production. Rapidly changing climatic conditions may thus alter the tempo and spatial pattern of masting of dominant species with potentially far-reaching ecological consequences. Understanding the future reproductive dynamics of ecosystems including boreal forests, which may be dominated by mast-seeding species, requires identifying the specific cues that drive variation in reproductive output across landscape gradients and among years. Here we used annual data collected at three sites spanning an elevation gradient in interior Alaska, USA between 1986 and 2011 to produce the first quantitative models for climate controls over both seedfall and seed viability in *P. glauca*, a dominant boreal conifer. We identified positive associations between seedfall and increased summer precipitation and decreased summer warmth in all years except for the year prior to seedfall. Seed viability showed a contrasting response, with positive correlations to summer warmth in all years analyzed except for one, and an especially positive response to warm and wet conditions in the seedfall year. Finally, we found substantial reductions in reproductive potential of *P. glauca* at high elevation due to significantly reduced seed viability there. Our results indicate that major variation in the reproductive potential of this species may occur in different landscape positions in response to warming, with decreasing reproductive success in areas prone to drought stress contrasted with increasing success in higher elevation areas currently limited by cool summer temperatures.

◆ **Roland, C.A., J.H. Schmidt, and E.F. Nicklen. 2013b**. Landscape-scale patterns in tree occupancy and abundance in subarctic Alaska. Ecol. Monographs. 83(1) 19-48.

Author abstract. Recent studies suggest that climate warming in interior Alaska may result in major shifts from spruce-dominated forests to broadleaf-dominated forests or even grasslands. To quantify patterns in tree distribution and abundance and to investigate the potential for changes in forest dynamics through time, we initiated a spatially extensive vegetation monitoring program covering 1.28 million ha in Denali National Park and Preserve (DNPP). Using a probabilistic sampling design, we collected field measurements throughout the study area to develop spatially explicit Bayesian hierarchical models of tree occupancy and abundance. These models demonstrated a strong partitioning of the landscape among the six tree species in DNPP, and allowed us to account for and examine residual spatial autocorrelation in our data. Tree distributions were governed by two primary ecological gradients: (1) the gradient from low elevation, poorly drained, permafrost-influenced sites with shallow active layers and low soil pH (dominated by Picea mariana) to deeply thawed and more productive sites at mid-elevation with higher soil pH on mineral substrate (dominated by Picea glauca); and (2) the gradient from older, less recently disturbed sites dominated by conifers to those recently affected by disturbance in the form of fire and flooding with increased occupancy and abundance of broadleaf species. We found that the establishment of broadleaf species was largely dependent on disturbance, and mixed forests and pure stands of broadleaf trees were relatively rare and occurred in localized areas. Contrary to recent work in nearby areas of interior Alaska, our results suggest that P. glauca distribution may actually increase in DNPP under warming conditions rather than decline as previously predicted, as P. glauca expands into areas formerly underlain by permafrost. We found no evidence of a shift to broadleaf forests in DNPP, particularly in the poorly drained basin landscape positions that may be resistant to such changes. Overall, our results indicate that probabilistic sampling conducted at a landscape scale can improve inference relative to the habitat associations driving the distribution and abundance of trees in the boreal forest and the potential effects of climate change on them.

◆ **Rowland, E.L. 1997.** The recent history of treeline at the northwest limit of white spruce in Alaska . Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 129 pp.

Author abstract. To understand how the northwestern-most treeline in Alaska has responded to changes in climate since the 19th century, I investigated the history and autecology of white spruce in two tributaries valleys of the Noatak River. A pollen record from Loon Lake extends back to ca. 6,000 years B.P. and indicates that spruce was growing around the mouth of the Kelly River (the middle Noatak Valley} by at least 1 ,900 years ago. Data collected from white spruce stands in the Kelly and Kugururok River valleys suggest that treeline in these areas became established within the last 600 years. Although the rate of recruitment in the spruce stands has been fairly steady throughout the last three centuries, recruitment did increase between A 0. 1920 and 1950 in response to the Northern Hemisphere temperature maximum. This response is evidenced by increased density in white spruce stands in valley bottoms and by the upslope movement of the altitudinal limit of spruce. The data from the study areas in the Kelly and Kugururok River valleys indicate that white spruce treeline has not extended beyond its current limit during the last 300 years.

◆ **Sanders, T. 2011.** Adaptive management in response to climate change: a synthesis of research findings and observations from the Pacific Northwest Forest. World Forest Institute, Portland, OR. 48 pp.

Author abstract. Temperature in the Pacific Northwest region (PNW) has warmed 0.7-0.9 ◦C since 1920 and is expected to increase further by the end of the century. Projected changes in regional precipitation are less certain than those for temperature. Overall, small decreases in summer precipitation and small increases in winter precipitation are predicted. Increases in greenhouse gas concentrations, especially CO2, are contributing to the warming of the atmosphere.

Elevated CO2 will impact forests both directly and indirectly. Tree growth, reproduction, and mortality are affected via the direct effects on the physiological processes of photosynthesis, respiration, and transpiration. Increased temperatures are expected to impact both the growth and regeneration stages of populations, whilst increases in the frequency of heavy precipitation events may increase the incidence of flood-related injuries.

Climate change can affect both the frequency and severity of disturbances that play a vital role in the natural dynamics of forests in the PNW. Events such as wildfires, insect outbreaks, diseases, droughts, windstorms and landslides profoundly influence ecosystem dynamics in terms of ecosystem structure, composition, and functioning.

Climate change will require trees to cope with new climatic and biotic environments. Populations of trees may cope with new climates by 1) adapting to new conditions in their current location (acclimate), 2) migrating to new locations, or 3) evolving in place (*in situ* evolution). If they cannot cope, they may disappear from local ecosystems altogether (extinction).

Silvicultural and genetic practices may be employed to assist in forest adaptation to climate changes, principally by influencing stand structure and species composition throughout stand development. The four management steps of review, rank, resolve and observe, considered iteratively, is an effective process for facilitating adaptation. Two case studies are used to illustrate how scientific research and land management agencies can cooperate to develop and implement adaptation options for assisting forest ecosystems to adjust to rapid climate change. The first describes adaptation strategies being used in the Olympic National Forest from a silvicultural perspective. The second is in the field of forest genetics, and refers to the Assisted

Migration Adaptation Trial (AMAT) being conducted in parts of British Columbia, and the states of Washington, Oregon, Idaho and Montana.

Barriers to adaptation include limited financial and human resources, policies that do not recognize climate change as a significant issue, and lack of an official science–management partnership. Information and tools needed to assist adaptation to climate can change hinge on this type of partnership.

Ten key strategies are highlighted as worthy of pursuing, and warranting further investigation in their potential for application in native forest management in Victoria, Australia. It is essential that dynamic and adaptive thinking is integrated into the way we make planning and management decisions, including our learning from changing conditions.

◆ **Tape, K. 2011.** Arctic Alaskan shrub growth, distribution, and relationships to landscape processes and climate during the 20th century. Unpubl. PhD thesis. Univ. of Alaska Fairbanks. 137 pp.

Author abstract. The primary change underway in the tundra of Arctic Alaska is the increase in air temperature and expansion of deciduous shrubs since 1980. I explored relationships between shrub expansion and relevant ecosystem properties such as climate, soil characteristics, erosion, and herbivory. Alnus viridis ssp. fruticosa (Siberian alder) shrubs located along streams, rock outcrops, or other features with active disturbance regimes showed a positive correlation between growth ring widths and March through July air temperature. Climate-growth relationships were much weaker for alder in adjacent tussock tundra. Additionally, tussock tundra sites had different vegetation composition, shallower thaw, lower mean annual ground temperature, lower mean growing season temperature, higher soil moisture, more carbon in mineral soil, and higher C:N values in shrub leaves than nearby non-tussock alder. Growth rings and site characteristics imply that preexisting soil conditions predispose alder shrubs growing in non-tussock tundra to respond rapidly to warming. Analysis of temporal series of aerial photography from 1950 and 2000 and of Landsat imagery from 1986 and 2009 showed an increase in percent cover of shrubs, primarily in riparian areas. This increase in shrubs is contemporaneous with a decline in peak discharge events from the Kuparuk River and a lengthening of the growing season since 1980, both of which may have caused the decline in sediment deposition observed in 3 of 4 lake sediment cores dated with lead and cesium isotopes. Both alder shrub growth and erosion are particularly sensitive to runoff dynamics during the snowmelt and green-up period, and these dynamics are affected by spring temperatures. Ptarmigan, moose, and hares forage heavily on shrubs protruding above the deepening snow during the late-winter, and selective browsing on willow vs. alder is likely influencing shrub community composition. The increase in shrubs during the 20th century may represent additional habitat for these herbivores, and herbivore-mediated changes in shrub architecture may have important implications for how shrubs trap snow and ultimately affect surface energy balance. Evidence from this thesis indicates shrub growth and cover have increased in response to persistent warming, particularly in areas where the organic layer is thinner and active layer deeper.

◆ **Thomson, A.M., C.L. Riddell, and W.H. Parker. 2009.** Boreal forest provenance tests used to predict optimal growth and response to climate change: 2. Black spruce. Canadian Journal of Forest Research, 2009, 39(1): 143-153, 10.1139/X08-167

Author abstract. Height, diameter, and survival data were obtained from 20 range-wide black spruce (Picea mariana (Mill.) BSP) provenance trials established from 1973 to 1977. Population response functions based on February minimum temperatures were developed for 23 Ontario and Great Lakes states provenances to predict climate values maximizing height growth for individual seed sources. Site transfer functions based on February maximum temperatures and May maximum temperatures were developed for five test sites to predict climate values maximizing height growth for test locations. Contour lines representing optimal performance were fitted to current (1961–1990) and future (2041–2070) climate grids. For black spruce seed sources from the east of Lake Superior and Lake Huron, optimal height growth was achieved between 45° and 47°N; for the western sources optimal performance moved north between 46° and 48°N. In eastern Ontario, height growth of northern sources may increase with transfer to warmer environments and with future temperature increases. Central sources are currently growing at or close to optimum and will be negatively affected by increased future temperatures. Southern sources may currently benefit from transfer to cooler environments, and the effects of global warming may cause significant height growth loss and the potential extirpation of local populations.

◆ **Ukrainetz, N.K., G.A. O'Neill, and B. Jaquish. 2011**. Comparison of fixed and focal point seed transfer systems for reforestation and assisted migration: a case study for interior spruce in British Columbia. Can. J. For. Res. 41(7):1452-1464.

Author abstract. In forestry, science-based seed transfer systems, the foundation of effective reforestation programs, will likely be used in some form to mitigate the negative effects of climate change. In this study, we developed fixed and focal point seed transfer systems for interior spruce (*Picea glauca* (Moench) Voss, *Picea engelmannii* Parry ex Engelm., and their hybrids) in British Columbia, Canada, and compared the effectiveness of both systems. Growth, phenology, and physiology traits were measured for 112 populations, and population means were transformed to principal components that were modeled using climate variables and multiple regression analysis. Compared with the fixed seed zone system, the focal point system had a greater area of seed use for a given risk of maladaptation. The relationship between growth and adaptive distance (i.e., adaptive similarity between test populations and populations local to test sites) was used to calculate critical seed transfer distances for focal point seed zones, which were defined according to expected forfeiture of growth. Changes in climate observed over the past 100 years and predicted in the next one third of a rotation were used to calculate appropriate assisted migration distances and develop methods for incorporating assisted migration into a focal point seed transfer system. [Link]

◆ **Van Cleve, K., W.C. Oechel, and J.L. Hom. 1990.** Response of black spruce (picea mariana) ecosystems to soil temperature modification in interior Alaska . Canadian Journal of Forest Research, 1990, 20(9): 1530-1535, 10.1139/x90-203

Author abstract. This paper reports results of a study designed to examine the control that soil temperature exerts on soil processes associated with nutrient flux, and in turn, on tree nutrition in interior Alaska black spruce ecosystems. Approximately 50 m^2 of forest floor in a 140-year-old black spruce ecosystem, which had developed on permafrost, was heated to 8–10 °C above ambient temperature. This perturbation amounted to approximately a 1589 degree-day seasonal heat sum (above 0 °C), 1026 degree-days above the control total of 563 degree-days. The forest floor, surface 5 cm of mineral soil, and soil solution were compared with those of an adjacent control plot to evaluate the change in nutrient content and decomposition rate of the forest floor. The nutritional response to soil heating of current black spruce foliage also was evaluated. Soil heating significantly increased decomposition of the forest floor, principally because of an increase in biomass loss of the O21 layer. The increased decomposition resulted in greater extractable N and P concentrations in the forest floor, higher N concentrations in the soil solution, and elevated spruce needle N, P, and K concentrations for the experimental period. These results are discussed in light of the importance of soil temperature and other state factors that mediate ecosystem function.

◆ **Walker, X. and J.F. Johnstone. 2014.** Widespread negative correlations between black spruce growth and temperature across topographic moisture gradients in the boreal forest Environ. Res. Lett. 9: 064016 (9pp)

Author abstract. The responses of tree growth to recent climate warming may signal changes in the susceptibility of forest communities to compositional change and consequently impact a wide range of ecosystem processes and services. Previous research in the boreal forest has largely documented negative growth responses to climate in forest species and habitats characteristic of drier conditions, emphasizing the sensitivity of drier or warmer landscape positions to climate warming. In this study, we explored relationships between climate and tree-ring growth of black spruce, a dominant tree species typical of cool and moist habitats in the boreal forests of North America. We assessed how these responses varied with stand characteristics and landscape position across four different regions in Alaska and Yukon Territory. Approximately half of the trees measured across regions and topographic gradients exhibited reduced radial growth in response to warm temperatures in the previous growing season and current spring, which we interpret as a signal of drought stress. Although we found considerable variation in the growth responses of individual trees within sites, landscape position and stand characteristics were weak predictors of this variability, explaining $\nleq$ 12% of the variation in any region. Our results indicate that future warming, particularly in spring, is likely to result in drought stress and a reduction of black spruce radial growth independent of region, landscape position, or stand characteristics. The occurrence of negative growth responses to temperature, even in cool and moist habitats, suggests that drought stress limitations may be more widespread in the northern boreal forest than previously anticipated, indicating broad sensitivity of ecosystem processes and services to climate change across a diverse range of habitat types.

◆ **Wang, T., E.M. Campbell, G.A. O'Neill, and S.N. Aitken. 2012**. Projecting future distributions of ecosystem climate niches: Uncertainties and management applications. For. Ecol. Manage. 279:128-140

Author abstract. Projecting future distributions of ecosystems or species climate niches has widely been used to assess the potential impacts of climate change. However, variability in such projections for the future periods, particularly the variability arising from uncertain future climates, remains a critical challenge for incorporating these projections into climate change adaptation strategies. We combined the use of a robust statistical modeling technique with a simple consensus approach consolidating projected outcomes for multiple climate change scenarios, and exemplify how the results could guide reforestation planning. Random Forest (RF) was used to model relationships between climate (1961–1990), described by 44 variables, and the geographic distribution of 16 major ecosystem types in British Columbia (BC), Canada. The model predicted current ecosystem distributions with high accuracy (mismatch rate = 4–16% for most ecosystem classes). It was then used to predict the distribution of ecosystem climate niches for the last decade (2001–2009) and project future distributions for 20 climate change scenarios. We found that geographic distributions of the suitable climate habitats for BC ecosystems have already shifted in 23% of BC since the 1970s. Consensus projections for future periods (2020s, 2050s, 2080s) indicated climates suitable for grasslands, dry forests, and moist continental cedar–hemlock forests would substantially expand; climate habitat for coastal rainforests would remain relatively stable; and habitat for boreal, subalpine and alpine ecosystems would decrease substantially. Using these consensus projections and data on the occurrence of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) in BC ecosystems, we estimated a twofold increase in seedling demand for this frost-sensitive, commercially important timber species, suggesting managers could begin planning to expand seed inventories and seed orchard capacity to more widely plant this species on logged sites. The results of this work demonstrate the power of RF for building climate envelope models and illustrate the utility of consensus projections for incorporating uncertainty about future climate into management planning. It also emphasizes the immediate need for adapting natural resource management to a changing climate. [Link]

◆ **Wendler G., M. Shulski**. **2009**. A century of climate change for Fairbanks, Alaska. Arctic 62(3): 295-300.

Author abstract: Climatological observations are available for Fairbanks, Interior Alaska, for up to 100 years. This is a unique data set for Alaska, insofar as it is of relatively high quality and without major breaks. Applying the best linear fit, we conclude that the mean annual temperature rose from -3.6˚C to -2.2˚Cover the century, an increase of 1.4˚C (compared to 0.8˚C worldwide). This comparison clearly demonstrates the well-known amplification or temperature change for the polar regions. The observed temperature increase is neither uniform over the time period nor uniform throughout the course of a year. The winter, spring, and summer seasons showed a temperature increase, while autumn showed a slight decrease in temperature. For many activities, the frequencies of extremes are more important than the average values. For example, the frequency of very low temperatures (below -40˚C, or -40˚F) has decreased substantially, while the frequency of very high temperatures (above 26.7˚C, or 80˚F) increased only slightly. Finally, the length of the growing season increased substantially (by 45%) as a result of an earlier start in spring and a later first frost in autumn. Precipitation decreased for Fairbanks. This is a somewhat counter-intuitive result, as warmer air can hold more water vapor. The date of the establishment of the permanent snow cover in autumn showed little change; however, the melting of the snow cover now occurs earlier in the spring, a finding in agreement with the seasonal temperature trends. The records for wind, atmospheric pressure, humidity, and cloudiness are shorter, more broken, or of lower quality. The observed increase in cloudiness and the decreasing trend for atmospheric pressure in winter are related to more advection and warmer temperatures during this season.

◆ **Williamson, T.B.; S.J. Colombo, P.N. Duinker, P.A. Gray, P.A, R.J. Hennessey, D. Houle, M.H. Johnston, A.E. Ogden, D.L. Spittlehouse. 2009.** Climate change and Canada's forests: from impacts to adaptation. Sustain. For. Manag. Netw. and Nat. Resour. Can., Can. For. Serv., North. For. Cent., Edmonton, AB. 104 p.

Author abstract: Climate change is already affecting Canada's forests. Current visible effects include changes in the frequency and severity of disturbances (such as fires, drought, severe storms, and damaging insect and disease attacks): other less visible changes such as change in the timing of spring bud burst are also underway. One of the consequences of future climate change will be further increases in the frequency and severity of extreme weather events and disturbances. Changes in productivity, species composition, and age- class distribution are also expected. Moisture and temperature are key factors affecting productivity. Productivity is likely to decrease in areas that are now or will become drier; productivity is expected to increase (at least in the near term) in northern areas that are currently limited by cold temperatures. An important consideration, however, is that genotypes tend to be finely adapted to local climates and potential productivity gains may not be realized if forest managers don't match genotypes to suitable climates. A higher percentage of the forests will be in younger age classes, and the frequency of early succession species and species adapted to disturbance will increase. Climatically suitable habitats for most species will move northward and will increase in elevation but the actual movement of species will lag behind the rate of movement of climatic niches. Climate change has implications for both current and future timber supply. The net impact of climate change on timber supply will vary from location to location. The recent mountain pine beetle event shows that climate-related factors can have dramatic effects on timber supply in a relatively short time period. Climate change will impact harvest operations. A significant portion of the harvest in Canada occurs in the winter when the ground is frozen. Harvesting on frozen ground allows for access to wetlands, reduces soil disturbance, and decreases costs of delivered wood. The magnitudes of change in climate that will be faced by Canada's forests and forest management sector and the consequent scale of expected impacts have no historical analogue. Canada's forest sector will need to adapt and it will need to do so without the benefit of prior experience. Forest managers can expect the unexpected and they can expect that change will be ongoing and unrelenting. Some general recommendations for beginning to address climate change in Canada's forest sector include enhancing the capacity to undertake integrated assessment of vulnerabilities to climate change at various scales; increasing resources to monitor the impacts of climate change; increasing resources for impacts and adaptation science; reviewing forest policies, forest planning, forest management approaches, and institutions to assess our ability to achieve social objectives under climate change; embedding principles of risk management and adaptive management into forest management; and maintaining or improving the capacity for communicating, networking, and information sharing with the Canadian public and within the forest sector.

◆ **Wilmking, M., G.P. Juday, V. Barber, and H. Zald. 2004.** Recent climate warming forces contrasting growth responses of white spruce at treeline in Alaska through temperature thresholds. Global Change Biology 10:1-13.

Author abstract. Northern and high-latitude alpine treelines are generally thought to be limited by available warmth. Most studies of tree-growth–climate interaction at treeline as well as climate reconstructions using dendrochronology report positive growth response of treeline trees to warmer temperatures. However, population-wide responses of treeline trees to climate remain largely unexamined. We systematically sampled 1558 white spruce at 13 treeline sites in the Brooks Range and Alaska Range. Our findings of both positive and negative growth responses to climate warming at treeline challenge the widespread assumption that arctic treeline trees grow better with warming climate. High mean temperatures in July decreased the growth of 40% of white spruce at treeline areas in Alaska, whereas warm springs enhance growth of additional 36% of trees and 24% show no significant correlation with climate. Even though these opposing growth responses are present in all sampled sites, their relative proportion varies between sites and there is no overall clear relationship between growth response and landscape position within a site. Growth increases and decreases appear in our sample above specific temperature index values (temperature thresholds), which occurred more frequently in the late 20th century. Contrary to previous findings, temperature explained more variability in radial growth after 1950. Without accounting for these opposite responses and temperature thresholds, climate reconstructions based on ring width will miscalibrate past climate, and biogeochemical and dynamic vegetation models will overestimate carbon uptake and treeline advance under future warming scenarios.

◆ **Wilmking M., Juday G.P., Terwilliger M., Barber V. 2006.** Modeling spatial variability of white spruce (Picea glauca) growth responses to climate change at and below treeline in Alaska - A case study from two National Parks. Erdkunde 60 (2):113-126.

Author abstract: Aim of this study was to develop a spatially explicit, medium-scale model of the climate sensitivity of recent white spruce growth at and below treeline in Denali National Park (DNP) and Gates of the Arctic National Park (GAAR) in Alaska and then use the model to project changes in extent of boreal forest under future warming scenarios. We developed a decision tree model to examine tree growth-environment relationships and used a GIS to extrapolate model results into space. In DNP our results indicate possible dieback of white spruce at low elevations and treeline advance and infilling at high elevations. If recent warming continues, the road corridor in DNP would experience forest increase of about 50%, mainly along the road decreasing the possibility for visitors to observe wildlife across open tundra. In GAAR our results indicate increased rate of white spruce growth at low elevation areas while other areas would experience changes in forest structure (dieback of tree-islands, infilling of existing stands). Changes in distribution of white spruce forests in Alaska are within the range of possibility on a regional scale (treeline advance, dieback). Structural changes within existing forest are possible on a medium (landscape) scale through changes in tree density, infilling and dieback. Changes in growth performance of individual trees due to climate warming are already underway, and further warming would intensify these changes with landscape-wide consequences.

◆ **Wimberly, M. C. and Z. Liu. 2013.** Interactions of climate, fire, and management in future forest of the Pacific Northwest. Forest Ecology and Management. In press, DOI: 10.1016/j.foreco.2013.09.043.

Author abstract. A longer, hotter, and drier fire season is projected for the Pacific Northwest under future climate scenarios, and the area burned by wildfires is projected to increase as a result. Fuel treatments are an important management tool in the drier forests of this region where they have been shown to modify fire behavior and fire effects, yet we know relatively little about how treatments will interact with changing climate and expanding human populations to influence fire regimes and ecosystem services over larger area and longer time periods. As a step toward addressing this knowledge gap, this paper synthesizes the recent literature on climate, fire, and forest management in the Pacific Northwest to summarize projected changes and assess how forest management can aid in adapting to future fire regimes and reducing their negative impacts. Increased wildfire under future climates has the potential to affect many ecosystem services, including wildlife habitat, carbon sequestration, and water and air quality. Fuel treatments in dry forest types can reduce fire severity and size, and strategically-placed treatments can help to protect both property and natural resources from wildfire. Although increased rates of burning are projected to reduce carbon stocks across the region, research to date suggests that fuel treatments are unlikely to result in significant increases in carbon storage. Prescribed burning combined with thinning has been demonstrated to be effective at reducing fire severity across a variety of dry forest types, but there is uncertainty about whether changing climate and increasing human encroachment into the wildland–urban interface will limit the use of prescribed fire in the future. Most fire research has focused on the dry forest types, and much less is known about the ecological impacts of increased wildfire activity in the moist forests and the potential for adapting to these changes through forest management. To address these knowledge gaps, future research efforts should build on the Pacific Northwest's legacy of integrated regional assessments to incorporate broad-scale climatic drivers with processes operating at the stand and landscape levels, including vegetation succession, fire spread, treatment effects, and the expansion of human populations into wildland areas. An important outcome of this type of research would be the identification of localized "hot spots" that are most sensitive to future changes, and are where limited resources for fire management should be concentrated.

◆ **Wolken, J.J. and T.N. Hollingsworth. 2012.** Alaska. Pages 205-209 (Appendix I: Regional Summaries, Alaska) in Effects of climatic variability and change on forest ecosystems: a comprehensive science synthesis for the U.S. forest sector. J.M. Vose, D.L Peterson, and T. Patel-Weynand (editors). USDA Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-870. Portland, Oregon. 265 p.

Author excerpt. Interior Alaska: In interior Alaska, the most important biophysical factors responding to changes in climate are permafrost thaw and changes in fire regime. The region is characterized by discontinuous permafrost, defined as ground (soil or rock) that remains at or below 0 °C for at least 2 years (Harris et al. 1988). Thawing permafrost may substantially alter surface hydrology, resulting in poorly drained wetlands and thaw lakes (Smith et al. 2005) or well-drained ecosystems on substrates with better drainage. Permafrost thaw may occur directly as a result of changes in regional and global climate, but it is particularly significant following disturbance to the organic soil layer by wildfire (fig. A1-2). As permafrost thaws, large pools of stored carbon (C) in frozen ground are susceptible to increased decomposition, which will have not only regional effects on gross primary productivity (Vogel et al. 2009) and species composition (Schuur et al. 2007) but also feedbacks to the global C system (Schuur et al. 2008).

The observed warmer air and permafrost temperatures have important societal impacts, because transportation, water and sewer, and other public infrastructures may be damaged (Larsen et al. 2008, Nelson et al. 2002). Recent changes in the fire regime in interior Alaska are linked to climate. The annual area burned in the interior has doubled in the last decade compared to any decade since 1970, with three of the largest wildfire years on record (fig. A1-2) also occurring during this time (Kasischke et al. 2010). Black spruce forests, the dominant forest type in the interior, historically burned in low-severity, stand-replacing fires every 70 to 130 years (Johnstone et al. 2010a). However, postfire succession of black spruce (*Picea mariana* [Mill.] Britton, Sterns & Poggenb.) forests has recently shifted toward deciduous-dominated forests with the increase in wildfire severity (Johnstone and Chapin 2006, Johnstone and Kasischke 2005, Kasischke and Johnstone 2005) and the reduction in fire-return interval (Bernhardt et al. 2011; Johnstone et al. 2010a, 2010b). With continued warming, changes in the fire regime will increase the risk to life and property for interior Alaskan residents (Chapin et al. 2008).

South-Central Alaska: South-central Alaska may be particularly sensitive to climate changes because of its confluence of human population growth and changing disturbance regimes (e.g., insects, wildfire, invasive species). Warmer temperatures have contributed to recent spruce beetle (*Dendroctonus rufipennis* Kirby) outbreaks in this region by reducing the beetle life cycle from 2 years to 1 year (Berg et al. 2006, Werner et al. 2006). Higher fuel loads resulting from beetle-caused tree mortality are expected to increase the frequency and severity of wildfires (Berg et al. 2006), which raises societal concerns of increased risks to life and property (Flint 2006). Most goods are shipped to Alaska via ports in south-central Alaska, so invasive plant species will probably become an increasingly important risk factor. Several invasive plant species in Alaska have already spread aggressively into Figure A1-2—In 2004, Alaska's largest wildfire season on record, the Boundary Fire, burned 217 000 ha of forest in interior Alaska. burned areas (e.g., Siberian peashrub [*Caragana arborescens*Lam.], narrowleaf hawksbeard [*Crepis tectorum* L.], and white sweetclover [*Melilotus alba* Medik.]) (Cortés-Burns et al. 2008, Lapina and Carlson 2004), and these could proliferate further with the increase in wildfire potential. Changes in surface hydrology in south-central Alaska have also been linked to warmer temperatures. In the Kenai lowlands, a subregion of south-central Alaska (fig. A1-1), many water bodies have shrunk in response to warming since the 1950s and have subsequently been invaded by woody vegetation (Klein et al. 2005). Recently, the rate of woody invasion has accelerated as a result of a 56-percent decline in water balance since 1968 (Berg et al. 2009). As a result of these combined effects of wetland drying and vegetation succession, wetlands are becoming weak C sources rather than strong C sinks, which has important consequences for the global climate system.

◆ **Wolken, J.M., T.N. Hollingsworth, T.S.Rupp, F.S.Chapin, III, S.F. Trainor, T.M. Barrett, P.F. Sullivan, A.D. McGuire, E.S. Euskirchen, P.E. Hennon, E.A. Beever, J.S. Conn, L.K. Crone, D.V. D'Amore, N. Fresco, T.A. Hanley, K. Kielland, J.J. Kruse, T. Patterson, E. A.G. Schuur, D.L. Verbyla, and J.Yarie. 2011.** Evidence and implications of recent and projected climate change in Alaska's forest ecosystems. Ecosphere art124. http://dx.doi.org/10.1890/ES11-00288.1

Author abstract. The structure and function of Alaska's forests have changed significantly in response to a changing climate, including alterations in species composition and climate feedbacks (e.g., carbon, radiation budgets) that have important regional societal consequences

and human feedbacks to forest ecosystems. In this paper we present the first comprehensive synthesis of climate-change impacts on all forested ecosystems of Alaska, highlighting changes in the most critical biophysical factors of each region. We developed a conceptual framework describing climate drivers, biophysical factors and types of change to illustrate how the biophysical and social subsystems of Alaskan forests interact and respond directly and indirectly to a changing climate. We then identify the regional and global implications to the climate system and associated socio-economic impacts, as presented in the current literature. Projections of temperature and precipitation suggest wildfire will continue to be the dominant biophysical factor in the Interior-boreal forest, leading to shifts from conifer- to deciduous-dominated forests. Based on existing research, projected increases in temperature in the Southcentral- and Kenai-boreal forests will likely increase the frequency and severity of insect outbreaks and associated wildfires, and increase the probability of establishment by invasive plant species. In the Coastal-temperate forest region snow and ice is regarded as the dominant biophysical factor. With continued warming, hydrologic changes related to more rapidly melting glaciers and rising elevation of the winter snowline will alter discharge in many rivers, which will have important consequences for terrestrial and marine ecosystem productivity. These climate-related changes will affect plant species distribution and wildlife habitat, which have regional societal consequences, and trace-gas emissions and radiation budgets, which are globally important. Our conceptual framework facilitates assessment of current and future consequences of a changing climate, emphasizes regional differences in biophysical factors, and points to linkages that may exist but that currently lack supporting research. The framework also serves as a visual tool for resource managers and policy makers to develop regional and global management strategies and to inform policies related to climate mitigation and adaptation.

◆ **Young, B. and A. Ogden. 2010.** Vulnerability and Adaptive Capacity of Yukon Tree Species to Climate Change: Summary Report.*in* Y. G. C. C. Secretariat, editor., Whitehorse, Yukon, Canada.

Author abstract. This summary sets out the key findings from the Vulnerability and Adaptive Capacity of Yukon Tree Species to Climate Change: Technical Report. This report was created as an initial component of a greater study in Yukon on assessing the vulnerability to climate change and adaptive capacity of Yukon forest tree species and ecosystems. The technical report provides a review and a synthesis of current scientific knowledge on the potential vulnerabilities and adaptive capacities of Yukon tree species to climate change.

Section 10
REFORESTATION MODELING

SUMMARY

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The creation of reforestation models typically employs the combination of field collected data with conceptual and mathematical models (Blanco et al. 2009). The majority of reforestation modeling within the boreal forest of Alaska has focused on relatively undisturbed sites where the regeneration processes are driven via gap dynamics and have been developed as forest growth and yield models (Liang and Zhou 2010; Liang 2010 and 2012; Liang, et al. 2012; and Young, et al. 2011). These models depict the processes of natural regeneration within small gaps in the forest formed when one or a few trees die relying on data that depict forest recruitment in terms of seedlings and sprouts becoming saplings. While this process is important in terms of potential replacement of the overstory it does not include information on new seedling recruitment following a disturbance (Young et al. 2011). In addition, these models have limitations due to the spatial resolution which they depict (between 1 and 4 km^2 for a given pixel size) resulting in complete homogeneity across a given pixel. The addition of data showing the establishment and growth of trees within a disturbed landscape would greatly enhance these models and allow for a greater understanding of the post disturbance dynamics.

A limited number of regeneration models within the boreal forest of Alaska have investigated regeneration following anthropogenic disturbance activities (Fox et al. 1984; Patel-Weynand and Gordon. 1999). A simulation study by Fox et al. (1984), indicated that there was a low probability of white spruce natural regeneration within previous logged sites in interior Alaska. While this was a very limited study in terms of its scope, field foresters in the region have typically agreed with these results, at least over the short term. An additional study which investigated forest regeneration following salvage logging of trees killed by the spruce bark beetle in the Copper River Valley and the Kenai Peninsula, demonstrates that prescribed burning has a large influence on both understory plant communities and spruce seedling regeneration (Patel-Weynand and Gordon 1999). Additional studies investigating post-harvest treatment within interior of Alaska are needed to further explore these dynamics.

Models predicting the current and potential future distributions of tree species across interior Alaska have also recently been developed (see Huettmann et al. 2008; Gray and Hamann 2013). These models provide a baseline on investigating species distributions and the coupling of these distributions with bioclimatic models so that future distributions under a range of potential climatic can be applied. The coupling of gap models, growth and yield models and species distribution models can lead to advances in our understanding of forest dynamics under both management and future climate scenarios.

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Author abstract. Natural regeneration is recognized as an important component of forest management. Field studies are usually combined with conceptual and mathematical models as the most effective way to understand and predict natural regeneration. In the case of the boreal forest, several important issues arise in the design of regeneration models and are reviewed here. The most important concerns the trade-off between complexity and portability. Complex models may mimic natural systems more closely than do simpler models, but this realism comes at a cost in terms of the volume of data necessary for their calibration. A second issue is that most regeneration models have been scaled to problems at the tree and stand level, but recent interest in landscape-level issues requires models applicable to this higher spatial scale. Finally, the conceptual framework underlying most regeneration models may need to be revisited in light of recent efforts to depict vegetation dynamics under changing climatic regimes. It is unlikely that any single modeling approach will prove adequate for modeling natural regeneration under all conditions, and we provided guidelines as to how to create effective regeneration models.

◆ **Fox, J.D., J.C. Zasada, A.F. Gasbarro, and R. Van Vedhuizen. 1984.** Monte Carlo simulation of white spruce regeneration after logging in interior Alaska. Canadian Journal of Forest Research, 1984, 14(5): 617-622, 10.1139/x84-112

Author abstract. Regeneration surveys on nine logged areas in the vicinity of Fairbanks, Alaska indicated low levels of white spruce (*Picea glauca* (Moench.) Voss.) regeneration. In view of the limited field data, Monte Carlo simulation methods were used to estimate the probabilities of obtaining various levels of white spruce stocking by the 1st and 10th years after logging. The simple model developed, combined the irregular seed production of white spruce with a declining seedbed availability to estimate quadrat stocking (4-m^2 plots). Results of simulation experiments indicated that the probability of achieving greater than 40% stocking with white spruce by the 10th postharvest year was 0.63. This result was sensitive to initial postharvest seedbed conditions and the frequency of good to excellent seed years and nonspruce revegetation rates. Both the field data and simulation results indicate the prospects of obtaining adequate white spruce restocking after timber harvest by unassisted natural regeneration were poor. However, simulation results also indicate that seedbed management may increase the probabilities of regeneration success significantly.

◆ **Gray, L. K. and A. Hamann. 2013**. Tracking suitable habitat for tree populations under climate change in western North America. Climatic Change 117:289-303.

Author abstract. An important criticism of bioclimate envelope models is that many wide-ranging species consist of locally adapted populations that may all lag behind their optimal climate habitat under climate change, and thus should be modeled separately. Here, we apply a bioclimate envelope model that tracks habitat of individual populations to estimate adaptational lags for 15 wide-ranging forest tree species in western North America. An ensemble classifier modeling approach (RandomForest) was used to spatially project the climate space of tree populations under observed climate trends (1970s to 2000s) and multi-model projections for the 2020s, 2050s and 2080s.We find that, on average, populations already lag behind their optimal climate niche by approximately 130 km in latitude, or 60 m in elevation. For the 2020s we expect an average lag of approximately 310 km in latitude or 140 m in elevation, with the most pronounced geographic lags in the Rocky Mountains and the boreal forest. We show that our results could in principle be applied to guide assisted migration of planting stock in reforestation programs using a general formula where 100 km north shift is equivalent to approximately 44m upward shift in elevation. However, additional non-climatic factors should be considered when matching reforestation stock to suitable planting environments.

◆ **Huettmann, F., B. Ohse, and S. Ickert-Bond. 2008.** Distribution of White Spruce in Alaska. An Open Access prediction surface from climatic and bioclimatic parameters using ESRI GRID formats. Data set. **URI:http://hdl.handle.net/11122/2577**

Author abstract. This open access data set contains a spatially gridded distribution of White Spruce in Alaska (ESRI GRID format), predicted from climatic and bioclimatic parameters (temperature, precipitation, elevation, and aspect). A species distribution model, developed by Bettina Ohse, was used to determine the ecological niche of the species based on the environmental variables. The model was developed within TreeNet, a classification and regression tree software. The ecological niche was then projected into geographical space, resulting in a predictive map of the species distribution in Alaska (4km resolution, tested accuracy of c. 95 %). We used ArcGIS 9.2. Data sources were freely available for the global public, and so were all tools used (prediction algorithms and specific GIS tools). We promote these data and this concept as a role model how to model plant distributions in wilderness areas and for overcoming data gaps in species distributions world-wide. We encourage the use and update of these data for further updating of this concept and its findings.

◆ **Liang, J.J. 2012.** Mapping large-scale forest dynamics: a geospatial approach. Landscape Ecology 27:1091-1108.

Author abstract. Digital map of forest dynamics is emerging as a useful research and management tool. As a key issue to address in developing digital maps of forest dynamics, spatial autocorrelation has been distinguished into ‘‘true’’ and ‘‘false’’ gradients. Previous ecological models are mostly focused on either ‘‘true’’ or ‘‘false’’ gradient, and little has been studied to simultaneously account for both gradients in a single model. The main objective of this study was to incorporate both gradients of spatial autocorrelation in a deterministic geospatial model to provide improved accuracy and reliability in future digital maps of forest dynamics. The mapping was based on two underlying assumptions—unit homogeneity and intrinsic stationarity. This study shows that when the factors causing the spatial non-stationarity have been accounted for, forest states could become a stationary process. A prototype geospatial model was developed for the Alaska boreal forest to study current and future stockings across the region. With areas of the highest basal area increment rate projected to cluster along the major rivers and the lowest near the four major urban developments in Alaska, it was hypothesized that moisture limitation and inappropriate human interference were the main factors affecting the stocking rates.

◆ **Liang, J.J., 2010.** Dynamics and management of Alaska boreal forest: An all-aged multi-species matrix growth model. For. Ecol. Manage. 260, 491-501.

Author abstract. Studies on the dynamics of Alaska boreal forest are sporadic and rare, and forest management in the region has been conducted in the absence of a useful growth model. This paper presents a matrix stand growth model to study the dynamics and management of Alaska's boreal forest, with harvests and artificial regeneration being accounted for. The model was calibrated with data from 446 constantly monitored permanent sample plots distributed across interior and south-central Alaska, and was tested to be accurate on an independent validation sample. The present model was applied on a most frequent commercial stand in interior Alaska to study a forest management regime that is being commonly used in the region. The simulation was for 300 years with a 40-year cutting cycle, and management outcomes under various permafrost levels and site elevations were investigated with sensitivity analysis. Despite the comparatively low financial returns, current management regime may generally benefit wildlife species by maintaining continuous forest cover and decent stand diversity, and properly managed forests had potential for timber production and wood-based energy. It was predicted by the model that both permafrost and site elevation had substantial impact on the management outcomes. Other variables being held constant at sample mean, net present value of harvests increased from $434 to $831 ha(-1) and the annual volume of harvest more than tripled from 1.68 to 5.75 m(3) ha(-1) y(-1) as permafrost declined from obvious to unlikely. Managers were also advised to focus on stands on medium elevation (300 m), as stands on lower or higher elevations were expected to produce less harvested volume and net present value. For rural Alaska communities suffering from expensive heating costs, it was suggested that approximately 20 ha of properly managed forest could sustain a household's annual heating requirement, while continuous forest coverage and decent diversity could still be maintained.

◆ **Liang, J. J. and M. Zhou. 2010.** A geospatial model of forest dynamics with controlled trend surface. Ecological Modelling 221:2339-2352.

Author abstract. This paper proposes a method of controlled trend surface to simultaneously account for large-scale spatial trends and non-spatial local effects. With this method, a geospatial model of forest dynamics was developed for the Alaska boreal forest from 446 constantly monitored permanent sample plots. The geospatial component of this model represented large-scale spatial trends in recruitment, diameter growth, and mortality. The model was tested on two sets of validation plots which represented temporal and spatial extensions of the current sample coverage. The results suggest that the controlled trend surface model was generally more accurate than both the non-spatial and conventional trend surface models. With this model, we mapped the forest dynamics of the entire Alaska boreal region by aggregating predicted stand states across the region. it was predicted that under current conditions of climate and natural disturbances, most of the Alaska boreal forest region may undergo a major shift from deciduous-dominant to conifer-dominant, with an average increase of 0.33 m(2) ha year(-1) in basal area over the Twenty-First Century.

◆ **Liang, J. J., M. Zhou, D. L. Verbyla, L. J. Zhang, A. L. Springsteen, and T. Malone. 2011.** Mapping forest dynamics under climate change: A matrix model. Forest Ecology and Management 262:2250-2262.

Author abstract. Global climate change may be affecting forests around the world. However, the impact of climate change on forest population dynamics, especially at the landscape or regional level, has hardly been addressed before. A new methodology was proposed to enable matrix transition models to account for climate impact on forest population dynamics. The first climate-sensitive matrix (CSMatrix) model was developed for the Alaska boreal forest based on observations from over 15 years of forest inventory. The spatially explicit model was used to map climate-induced forest population dynamics across the region. The model predicted that the basal area increment in the region under natural succession would be hindered by global warming, more so for dry upland areas than for moist wetlands. It was suggested that temperature-induced drought stress could more than offset a predicted increase of future precipitation in the region to lower overall forest productivity. At the same time, stand diversity would increase across the region through transient species redistribution. Accounting for climate conditions made the CSMatrix model more accurate than conventional matrix models.

◆ **Patel-Weynand, T. and J.C. Gordon. 1999.** Modeling succession patterns, forest health and adaptation in spruce beetle (*Dendroctonus rufipennis* Kirby) infested ecosystems on the Kenai Peninsula, Alaska. pp. 43-50 in: Proc. of the Alaska Reforestation Council April 29, 1999 Workshop. Anchorage, AK. Univ. of Alaska Fairbanks Agric. & For. Exp. Sta. Misc. Publ. 99-8. 85 pp.

Author abstract. Extensive loss of old growth habitat, increased ecosystem fragmentation and lack of natural regeneration constitute the largest ecological crisis facing Alaska's forests today. By 1993, spruce beetles (*Dendroctonus rufipennis* Kirby) had infested 725,000 acres in south-central Alaska, and mortality was projected on more than 1.1 million acres the following year (Alaska SAF 1993). Mortality rates climbed much higher by 1997, and the infestation became the largest in North America. Several of Alaska's resource values were reduced as the forest cover was killed in large portions of entire drainages. Wildlife, water quality, aesthetics, and long-term productivity were affected, and research was initiated to quantify the impacts.

Forest succession, adaptation, and health were studied to determine long-term ecosystem sustainability, and resilience and resistance to anthropogenic and natural disturbances. In 1997, 30 plots were established in beetle-killed Lutz spruce (*Picea* x*lutzii* Little) communities in Juneau and Daves creeks at Cooper Landing on Kenia Peninsula. Four management regimes: slash, burn, whole tree removal and nitrogen, and an untreated control were applied to the plots. Stands and tree characteristics were measured, and litter baskets were installed on all plots. Understory vegetation collected during the 1998 field season is being analyzed for biomass and nutrient contents. Soils were sampled for organic matter and nutrient analysis. Preliminary results indicate that improved nutrition and light increased bluejoint grass (*Calamagrostis canadensis* (Michx.) Beavu.) biomass in the nitrogen, burn, and tree removal treatments.

◆ **Rupp, T.S. 1997.** A Geographic Model of Landscape-Level Post-Disturbance Forest Establishment Patterns of Interior Alaska White Spruce Ecosystems. Aspen Bibliography. Paper 1390. http://digitalcommons.usu.edu/aspen_bib/1390

Author abstract. A geographic model of early post-disturbance forest establishment patterns, Alaskan Boreal Forest Establishment Model (ABFEM), is described for white spruce ecosystems in interior Alaska. The model has been created within the GRID environment of ArcInfo, utilizing a complex set of AML's. ABFEM simulates the production of seed, dispersal of seed, disturbance effects upon the seedbed, vegetative reproduction potential, and the early establishment patterns of tree seedlings within a burnt upland white spruce ecosystem. The spatially explicit model can simulate regeneration dynamics upon a defined landscape unit. The model realistically simulated seed dispersal and seedling establishment patterns of white spruce following the 1983 Rosie Creek fire, 20 km southwest of Fairbanks. An example of application of the model to forest management is presented.

Section 11
REGENERATION ASSESSMENT AND TECHNOLOGY

SUMMARY

Marty Freeman, Alaska Department of Natural Resources, Division of Forestry

This section includes references on methods for assessing reforestation results after timber harvests. Current methods used by the Alaska Division of Forestry are described in ADNR, 2008. Brand et al. (1991) discuss options for designing ground or aerial regeneration surveys to provide useful management information. Patterson (2001) presents complementary information on regeneration surveys and stocking standards from Alberta.

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◆ **Alaska Department of Natural Resources Division of Forestry. June 2008.** Reforestation Handbook. Unpublished. 31 pp.

Author abstract: This handbook establishes DNR Division of Forestry policies and methods for the planning and evaluation of reforestation under the Forest Resources and Practices Act. It includes standards for regeneration stocking surveys, seedling distribution maps, regeneration survival checks.

◆ **Alaska Department of Natural Resources Division of Forestry. 1985.** Reforestation Handbook. Unpublished manual. Dept. of Natural Resources—Division of Forestry. State of Alaska Forest Management Handbook. Chapter 3162. Dec. 1985. 42 pp.

Compiler abstract. This is an early edition of the DOF Reforestation Handbook, including DNR Division of Forestry policies and methods for the planning and evaluation of reforestation under the Forest Resources and Practices Act. It includes standards for regeneration stocking surveys, seedling distribution maps, regeneration survival checks. At the time of this edition, the acceptable stocking standard for Regions II and III was 500 trees/acre. The time frame to reach that standard was 7 years in Region II and 10 years in Region III.

◆ **Brand, D.G., Leckie, D.G., Cloney, E.E., 1991.** Forest regeneration surveys: Design, data collection, and analysis. The Forestry Chronicle 67, 649-657.

Author abstract. Regeneration surveys have always been looked on as a necessary evil in silviculture. Huge amounts of data have been collected, only to answer simple questions or to be filed and never used. This paper addresses the possibility of changing regeneration surveys from simple legislative requirements, into components of the forestry information system. Current technology allows the development of sophisticated decision support systems, and this changes the whole perspective on information needed from regeneration surveys. Depending on the level of information needed, ground surveys or aerial surveys can be used. The types of information available from different survey systems are described, and two case studies are presented. In one, regenerating stands are assessed using an intensive ground-based survey and, in the second, the MEIS (Multi-spectral, Electro-Optical Imaging Scanner) is used to identify stocking in young plantations. It is concluded that surveys must be designed by working backwards from the decisions to be made, to the information needed to make those decisions, to the data needed to provide that information.

◆ **Patterson, D.J. 2001.** Assessment procedures and reforestation standards for boreal forest regeneration. PowerPoint presentation to the Alaska Reforestation Council, May 23, 1001. 54 slides.

Compiler abstract. This presentation summarizes the purpose, design, and timing of regeneration surveys, equipment needs, and surveyor qualifications, based on experience from the Province of Alberta. It also reviews Alberta stocking standards and criteria for coniferous, mixed-wood, and deciduous stands. The presentation discusses a decline in conifer stand stocking between 10 and 20 years after regeneration. Crowding from aspen regeneration, hare browsing, and *Calamagrostis* competition were contributing factors.

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